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Techniques to better exploit the possibilities of wire-rope testing with electro-magnetic instruments

L.B. Geller and F. Kitzinger

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MICROMEDIA

TECHNIQUES TO BETTER EXPLOIT THE POSSIBILITES OF WIRE ROPE TESTING WITH ELECTRO-MAGNETIC INSTRUMENTS

by

L.B. Geller* and F. Kitzinger**

ABSTRACT

This paper constitutes part of a series of reports describing the results of an extensive CANMET project. The latter was undertaken to examine, document, and analyse the reasons for mine-shaft wire-rope failures that continue to occur despite mandatory rope-examinations at regular intervals, with EM test instruments.

In this report the authors discuss little known, as well as novel, test-procedures which widen the range of the hitherto practised EM measuring techniques. In particular the authors deal with: (a) the measurement of total metallic cross sectional rope-areas — rather than the standard procedure of loss-of-metallic-area (LMA) strip-chart readings, as obtained relative to a 100% benchmark reference-level (i.e., the level of the 'best' rope segment); in this context another important subject, namely that of the legitimacy of comparing LMA chart-readings obtained with different instrument calibrations, is also dealt with; (b) the calibration of an electro-magnetic (EM) instrument's Local Fault (LF) measuring section — rather than the usual practice of obtaining uncalibrated LF chart-traces, and (c) a proposed method for calculating loss-of-breaking-strength (LBS) values from an EM instrument's LMA and LF chart-traces.

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Keywords: Wire-ropes; Non-destructive-testing; Electro-magnetic instruments; Total loss-of-metallic rope area; Local-fault chart-trace calibration; Loss-of-strength calculation

TECHNIQUES POUR MIEUX EXPLOITER LES POSSIBILITÉS DES ESSAIS DE CÂBLES MÉTALLIQUES AU MOYEN D'INSTRUMENTS ÉLECTROMAGNÉTIQUES

par

L.B. Geller* et F. Kitzinger**

RÉSUMÉ

Le présent document constitue une partie d'une série de rapports décrivant les résultats d'un projet ambitieux de CANMET. Ce dernier a été lancé pour examiner, documenter et analyser les causes des ruptures de câbles métalliques dans des puits de mine qui continuent de se produire malgré les examens de câbles imposés à des intervalles réguliers, au moyen d'instruments d'essai électromagnétiques.

Dans le présent rapport, les auteurs traitent de méthodes d'essai tant nouvelles que méconnues qui viennent élargir la gamme des techniques de mesure électromagnétique en usage jusqu'à ce jour. Ils ont notamment traité: a) de la mesure de la section totale des câbles métalliques plutôt que de la méthode classique des enregistrements sur bande de papier de la perte de section métallique (PSM), tels qu'obtenus par rapport à un niveau de référence de laboratoire de 100 % (niveau du "meilleur" segment du câble); à cet égard, un autre aspect important, la légitimité de comparer les enregistrements de PSM de divers étalonnages d'instrument, est aussi examiné; b) de l'étalonnage de la section de mesure comportant un défaut localisé (DL) d'un instrument électromagnétique - plutôt que de la pratique habituelle des enregistrements DL non étalonnés, et c) une méthode proposée pour calculer les pertes de résistance à la rupture (PRR) d'un instrument électromagnétique.

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Mots clés: câbles métalliques; essai non destructif; instruments électromagnétiques; perte de section de câble métallique totale; étalonnage des enregistrements de sections à défauts localisés; calcul de la perte de résistance

LIST OF ABBREVIATIONS

ABBREVIATION	MEANING
CANMET —	Canada Centre for Mineral and Energy Technology
EM —	Electro-magnetic
ID —	Internal Diameter
LBS —	Loss of Breaking Strength
LC —	Locked Coil
LF —	Local Fault
LMA —	Loss of Metallic Area
MA —	Metallic cross-sectional Area
MRL —	Mining Research Laboratories
mV —	milliVolt
NDT —	Non Destructive Testing
OD —	Outside Diameter
R&D —	Research and Development
RMA —	Remaining Metallic Area
RS —	Remaining Strength
TMA —	Total Metallic Area
1988 09 09 —	dates given in following order: year; month; day

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INTRODUCTION

Electro-magnetic (EM) wire-rope testers, in one form or another, have been in use for several decades now. They have proven to be very helpful instruments, providing reliable and remarkably repeatable results of considerable practical value. Unfortunately, mine-shaft rope failures continue to occur, despite mandatory rope-examinations with EM testers at regular intervals.

A CANMET project was undertaken in 1986 in response to requests by both the mining industry and the mine regulatory authorities, to examine, document, and analyse the reasons for these untoward incidents. This work included both in-house and contracted phases. Results were published in a series of CANMET reports. To date these include references 1 through 14. Others are to follow. In essence it was established that the failures, on the whole, were of a human rather than of a hardware related origin. Consequently, it was recommended that instrument operating, as well as strip-chart evaluating, techniques be taught on a much more uniform, wider, and more thoroughgoing basis.

This report constitutes part of the aforementioned series of CANMET publications. However, it differs from the previous reports somewhat, insofar as in it the authors discuss little known, as well as novel, test-procedures, rather than concentrating on the errors committed when employing more-or-less standard practices. Specifically, in this paper the authors deal with: (a) the measurement of <u>total</u> metallic cross-sectional rope areas and related problems, such as the legitimacy of comparing LMA chart-readings obtained with different instrument calibrations, and the problem of correct strip-chart alignment and splicing, (b) the calibration of an EM instrument's LF sensing section, and (c) a proposed method for calculating LBS values from an EM tester's LMA and LF chart-traces.

MEASUREMENT OF TOTAL METALLIC CROSS SECTIONAL AREAS

<u>General remarks</u>

Most designers of electro-magnetic (EM) wire-rope testers developed their instruments to detect changes in the metallic cross-sectional area (MA) of the ropes with reference to a rope-section along which the instrument had been calibrated at the commencement of testing. Deviation of the rope's MA from that of the calibration-section is commonly known as loss-of-metallic area (LMA). However, unless the instrument happened to be calibrated at the 'best' rope-section — i.e., along the one whose MA

is closest to that of the rope's original, 'as manufactured', MA — the LMA chart-trace may show increases (besides decreases) in the rope's MA. Common operator practice is to designate the point of greatest MA, as indicated on the LMA chart-trace, as the "100% reference level". All MA losses are measured relative to it. Even if one tacitly assumes that, in practice, there is no instrument design related shift of this point (at least none of any consequence) throughout the entire period of a rope-test, there remain at least two significant problems with the aforementioned process, namely: (1) that if the 'best' rope section should have been reduced by wear, corrosion, etc., the LMA chart-readings will underestimate the actual LMA at any given rope-section by the amount of this deterioration, and (2) that in current operational practice no attention seems to be paid to the differences in %LMA chart-readings that arise if the EM tester is calibrated along rope segments with different amounts of LMA.

The question arises whether, and if so how, these shortcomings may be overcome with commercially available EM wire-rope test-instruments. This report describes methods of doing so, within the confines of certain limitations. In particular, due to time and budgetary constraints, our complete series of tests were conducted with only one (the Magnograph) of the five EM instruments that were used during CANMET's extensive test-series. Consequently, our present report is limited to results obtained with this instrument.

Experimental procedure

(1) Measurement of instrument response vs total-metallic-area (TMA)

Contrary to usual procedure in case of operational measurements, our experimental procedure began with an empty sensor-head. The purpose was to record instrument-response over the entire operating range of the sensor (i.e., from zero metallic weight to the maximum specified rope-size). Next our experimental procedure consisted of filling the empty sensor-head with straight ferro-magnetic rods of known metallic cross-sectional area, and of a length (some 3 ft in our case) that is well in excess of the sensor-head-length. In doing this it is important to simulate the actual conditions that arise when a real wire-rope is placed along the axis of a sensor-head. While filling the sensor-head we took note of the output voltage (mV) of the LMA channel. The resultant voltage, as a function of total cross-sectional metallic-area (expressed as kg/m), is plotted in Figures 1a to 1e for the case of a Magnograph tester (serial #80-04).

While only the latter instrument was readily available to us for the required length of time, we undertook preliminary tests with an LMA-250 tester as well. Photographs illustrating testing in progress are shown in Fig. 2.

(2) Discussion of Magnograph results

Our tests were undertaken with different instrument-inserts, designated as "Insert A" to "Insert E". These inserts are ferromagnetic extensions of the pole pieces. Their principal purpose is to minimize air-gap losses within the magnetic circuit of the measurement system. As described in the Magnograph's Operating Manual: Insert 'A' is used for rope sizes $\frac{1}{2}$ to $\frac{3}{4}$ in.; 'B' for $\frac{3}{4}$ to $1\frac{1}{8}$ in.; 'C' for $1\frac{1}{8}$ to $1\frac{9}{16}$ in.; 'D' for $1\frac{9}{16}$ to $1\frac{7}{8}$ in.; and 'E' for $1\frac{7}{8}$ to $2\frac{1}{2}$ in.

As can be seen in Figures 1a to 1e, to begin with the correlation between total MA and the measured voltage (mV) is linear, with all the inserts. However, as the measured wire-rope diameter is enlarged, it becomes increasingly difficult to completely saturate the rope's metallic cross-section magnetically. Consequently, around the 3 kg/m mark the curves exhibit a departure from linearity, due to the lower relative levels of magnetic saturation of larger wire-rope sizes. To avoid this departure from linearity the size and weight of the permanent magnets in the sensor-heads would have to be increased with increasing rope-sizes and weights. All instrument designers are faced with this problem; to date all had to compromise on this point, so as to avoid having to use inordinately heavy permanent magnets. In case of the Magnograph, for example, the present weight of the sensor-head (some 105 lb) would have to be increased about five times to achieve linearity up to its limiting rope-size of 16 kg/m — obviously a practical *non sequitur*. In any case linearity is not a prerequisite for achieving measurements of total MA with EM instruments, as long as the correlation between the true MA and the output mV is both known and repeatable, as we, in this report, show it to be in case of the Magnograph.

Figures 1a to 1e were obtained with the serial #80-04 Magnograph. Each Magnograph must, however, be tested individually, because voltage-output vs kg/m may vary from instrument to instrument. As an example, there is a noticeable difference between the corresponding calibration-chart values obtained with the serial #80-04 and #81-01 Magnographs. Nonetheless, the overall correlation will always be the same, since it is a function of the magnetic circuit, which is the same for all Magnographs.

The first step of the standard operational procedure – with the Magnograph sensor-head installed around the rope — involves adjusting the LMA-zero potentiometer with the appropriate instrument dial, to show zero on the LMA meter. This dial

operates a 10-turn potentiometer. In case of our laboratory tests the resultant LMA-zero potentiometer dial readings 'X', after the LMA-zero has been set, are plotted on the right-hand ordinate of Figures 1a to 1e. In case of a specific operational situation the current state of the rope that is being tested can be obtained by horizontally projecting whatever value 'X' has been found to be appropriate (by standard procedures) onto the MA (kg/m) vs mV calibration-curve, and then by raising the accordant ordinate on the kg/m abscissa. The difference between this latter value, and the original kg/m value that is known to apply to the particular wire-rope currently being tested, provides the sought after information, namely: the amount of LMA that needs to be added to all chart-readings in order to compensate for the rope-wear that occurred at the calibration-section.

In practice, Magnograph owners can proceed as follows:

(1) either they can custom calibrate their own instrument, by following the steps of the foregoing procedure, or

(2) they can make use of the manufacturer's operating manual, which contains the calibration-curves for the particular instrument the manual was supplied with. These curves are provided separately for the various instrument-inserts, and for different rope-constructions. A sample diagram, obtained from a Magnograph's operating manual, is shown in Figure 3. It may, incidentally, be noted that by using these calibration-curves, the resultant chart-traces are calibrated at 2.5% LMA per major strip-chart division.

    The owners need, therefore, only follow the manufacturer's instructions regarding instrument calibration for the specific rope and insert in question. Upon obtaining the value of their LMA-zero dial reading, they need to enter it on the left-hand 'Zero-dial' ordinate of their respective calibration diagrams, and then project it horizontally onto the manufacturer's 'zero' curve. From here a vertical projection onto the kg/m abscissa will provide the sought after kg/m metallic weight, appropriate for the actual rope-segment and rope-conditions along which the instrument is being calibrated. Thus, the loss at the calibration-section due to wear, corrosion, etc. — and thereby the necessary LMA corrections to the chart-readings — can be obtained for the specific Magnograph and wire-rope in question.

The possibility of total MA measurements with EM instruments other than the Magnograph depends on the basic design details of the instrument in question, specifically upon its magnetic and electronic circuits. Magnetic saturation limitations may be

of particular importance. Some instruments, by design, are capable of measuring only a relatively small MA deviation. This is perfectly satisfactory when only the LMA, typically some 10% to 15%, needs to be determined. If, however, a greater deviation than the originally designed range arises, electrical circuits may suffer overloading. To measure TMA it may be necessary to cover eight to ten times the range required for LMA determinations. The need for an appropriate warning signal in case of electronic circuit saturation — such as a light recommended in an earlier CANMET report (5) — is particularly manifest in the foregoing situation.

(3) Examples, to illustrate the foregoing procedure

During the course of the CANMET research project, referred to earlier, an exceptional amount of test-data was obtained. These data include information needed to illustrate the above described procedure for measuring a wire-rope's total metallic cross-sectional area with a Magnograph tester. Relevant examples are provided in this report's Appendix 1. While, unfortunately, these data proved to be unreliable in quantitative terms, they illustrate at least two important points, namely: (1) how our method of TMA measurement is to be applied, and (2) that utmost care must be taken throughout the wire-rope testing process, if reliable results are to be obtained.

Theoretical considerations

Being able to measure total metallic cross-sectional areas permits us to discuss two important additional subjects about which little, if anything, appears to have been published. These subjects involve the question of how proper it is to compare %LMA chart-readings without concurrent consideration of the respective instrument-calibration details as well. Specifically, in Appendix 2, we examine the situations that arise: (1) in case of consecutive tests, possibly some six or more months apart, during which time the rope segment along which the instrument had previously been calibrated has seriously deteriorated, and (2) in case of same-day tests involving, however, two instrument set-ups along different rope-segments, or, perhaps, two test runs with ascending and descending rope travels.

While in these cases we do not refer to actual quantitative test-results, we do base our observations on operational rope-conditions and test-reports — namely: (a) of reference 8 in case of point (1), and (b) of reference 6 in case of point (2) — even if we do use theoretical linear rope-density (kg/m) and %LMA data for illustrative purposes.

In either of the foregoing cases the operational problem can arise of having to calibrate twice, possibly along two different rope segments of considerably differing quality. If possible this should be avoided, for example: (a) by moving the instrument's sensor-head without recalibration (should this option be feasible, as it is with the Magnograph), or (b) by recalibrating along the same overlapping rope segment along which the initial calibration had been effected. Should, however, neither of the foregoing options be feasible — either due to instrument design problems, or to rope-accessibility problems — the procedures described in Appendix 2 should be followed in order to obtain legitimate chart-comparisons, and/or proper alignment and splicing, of different chart-segments. In any event proper alignment, and splicing, is greatly facilitated by temporarily taping a calibration wire to the rope being tested, at the appropriate location. This was done, for example, by Rotesco Ltd. (see Fig. 10, after Fig. 2a of ref. 12).

CALIBRATION OF AN EM INSTRUMENT'S LF SECTION

General remarks

When performing NDT measurements with EM instruments it is important that the instruments' gain and sensitivity settings be manually recorded on the respective charts. This is important so that consecutive measurements of the same rope can be properly evaluated and legitimately compared.

When following our proposed procedure for calibrating the instruments' LF section, the peak-to-peak amplitude reading of the characteristic waves represents a measure of the instrument's gain-setting. It also provides a benchmark for evaluating surface faults.

Calibration procedure

To calibrate the EM instrument's LF section (including the magnetic* and electronic circuits, and the chart-recorder setting) the following procedure is recommended:

(1) use a ferro-magnetic wire of 0.062 in. diameter and 3 ft length. Cut the wire at its centre at right-angle to its axis, and provide a 0.3 in. gap. This gap can be maintained if the wire is inserted in a non-magnetic tube with an I.D. close to

* if the Magnograph is set to the 'static', rather than the 'dynamic', mode

the wire's O.D. Maintain the gap with a non-magnetic spacer. The wire should be glued into place, so as to form a rigid assembly. We refer to this assembly as the "LF Calibration Rod";

(2) on moving this calibration rod back and forth through the sensing head, a characteristic waveform is generated (Fig. 4). Note that the amplitude of these waves is unaffected by the speed with which the rod is moved back and forth, i.e., the trace is speed-independent. The peak-to-peak amplitude of this LF signal represents the effect of a magnetic dipole, with a flux density variation of 6.4 Gauss, passing through the sensor-head. In fact, it represents a 0.062 in. diameter broken wire with a 0.3 in. end-separation. An LF calibration rod with these dimensions can be used with the Magnograph at any LF gain settings, without the recorder pen leaving the strip-chart.

Similar techniques can be used with other EM instruments, but appropriate dimensions of the test pieces must first be established. Moreover, the LF signal's speed-independence must be verified; this instrument characteristic might not always apply.

Benefits of the foregoing procedure include the following:

(a) verification of proper operation of the LF sensor; i.e., by moving a calibration-rod through the sensor-head one can ascertain that the instrument is in good working order;

(b) the procedure, as described, produces an LF trace amplitude that depends on the specific system being used. We have a calibrated signal-amplitude. In other words, we now have a record of the LF gain-setting that was used;

(c) the availability of a calibrated LF signal is important when developing a better LBS estimating method than the currently available ones;

(d) on the basis of the proposed calibration procedure, (i.e., on the basis of figures such as Fig. 4), we can also establish whether the operational LF trace perturbation represents: (1) a big signal with a low gain setting, or (2) a low signal with a high gain setting. Relevant conclusions, regarding a specific LF trace, can, therefore, be drawn.

LMA AND LF CHART-TRACE BASED LBS ESTIMATES

General remarks

Several provincial mine regulations in Canada stipulate that mine-shaft wire-ropes be discarded, inter alia, when their original breaking strength is found to have decreased by a specified percentage. In practice this LBS drop is usually established by means of routine non-destructive testing with EM instruments. As pointed out in previous CANMET reports (e.g., see references 1, 2, 3, 7), and elsewhere, the practice of estimating LBS values on the basis of the measured LMA and LF signals of dual-function EM testers is fraught with major difficulties. Not the least of these is the lack of published information on how to proceed with the relevant calculations. During the course of the CANMET's current R&D project on wire-rope testing several instrument operators submitted LBS estimates, while others refused to do so on the grounds that such practice cannot be substantiated. As to the LBS estimates that were submitted to CANMET:

(1) the ones by the Rotescograph operator were obtained by doubling the respective %LMA chart-readings, irrespective of any other test conditions, while

(2) those of the Rotesco AC operator were based on tabulated factors with which the respective %LMA chart-readings had to be multiplied, in order to obtain the %LBS estimates. These factors ranged from 1.51 to 2.00, as a function of different rope sizes ($\frac{3}{4}$ in. to $2\frac{1}{4}$ in.).

(3) the Magnograph operator based the reported LBS estimates on a method developed by this instrument's manufacturer (15). It involved a quantitative assessment of both the LMA and LF chart-traces actually obtained. We describe the outlines of this process hereunder, without evaluating its accuracy, other than to agree with the overall principles of the method.

The Magnograph operator's method

(A) Background information

The manufacturer's initial LBS calculations were based on strength-loss data obtained with stranded ropes. An average relationship between estimated and actual LBS data was then developed by grouping the available test-results into specific sub-groups of increasing LBS value. This process yielded the following relationships:

$$R.S. = 0.0157 \times (RMA)^2 - 0.551 \times (RMA) \qquad Eq.\ 1$$

for 90% < RMA < 98%, or

$$R.S. = RMA \times (F1) \qquad Eq.\ 1a$$

with

F1 = 0.0157 (RMA) – 0.551;
RMA = remaining metallic area, and
R.S. = remaining strength.

The foregoing relationships still resulted in large variances. A study of the existing literature by the Magnograph's manufacturer — regarding the AC tester's results in the 1950's and 1960's — is said to have shown that variations in the AC instrument's inductive output was converted to metallic area-loss by the use of a number of factors which compensated for the AC tester's non-linear response of inductive output vs metallic rope-weight. The conclusion drawn, and confirmed by field tests, was that the metallic-area measurements obtained with the Magnograph, and those reported for the AC tester, should be quite close together.

(B) Additional use of the Magnograph's LF channel

A review of the initial LBS tests showed that there was some general relationship between the size of the signal recorded on the Magnograph's LF chart-trace, and the actual strength-loss of the relevant rope-sample. Specifically, for samples with high LF signal levels, a higher strength-loss was found for a given amount of metal-loss. The reason for this trend was found on disassembling, and visually inspecting, the test-samples in question. This inspection process revealed that the high LF signals were generated by localized wear and corrosion pitting. These tended to be more severe over short rope sections separated by, approximately, one lay-length.

The Magnograph manufacturer's modelling of the measured LF and LMA chart-traces began with the assumption that the average relationship expressed in Eq. 1 was true for a specific LF level, and that this level was related to the amount of the LMA. The specific LBS was then assumed to be lower if the actual LF levels were lower than a typical value, or higher in the reverse case. Here LF levels were designated as being the average peak-to-peak value of the chart-trace over an 8 to 9 ft rope-stretch. The latter distance was chosen so as to reflect the distributed way in which fracture occurs in a destructive test, and also in order to provide a sufficient number of data-points for calculating an acceptable average value. To use the information provided by the LF chart-trace, it was assumed that LBS could be modelled as follows:

$$Typical\ LF\ Level\ =\ LMA \times (A) + (B) \qquad Eq.\ 2$$

where (A) and (B) are functions of rope size, and

$$Correction\ Factor\ F3\ =\ 1 - \frac{Actual\ LF\ level}{Typical\ LF\ level} \qquad Eq.\ 3$$

where 'Typical LF level' in Eq. 3 is the one obtained in Eq. 2. Also,

$$Modified\ Estimating\ Factor\ F2\ =\ [1 - F1] \times [F3] + F1 \qquad Eq.\ 3a$$

and

$$Modified\ R.S.\ =\ RMA \times F2 \qquad Eq.\ 4$$

By using the aformentiond approach on some 30 to 40 test pieces, the numerical values of (A) and (B) in Eq. 2 could be generated pragmatically. It was also observed that the results proved more accurate whenever the peak-to-peak LF values, used to calculate the average, contained a maximum peak approximately twice that of the average value. In situations when the peak value was considerably greater than, or less than, twice the average, the resulting LBS estimates tended to be greater, or less than, the value represented by Equations 1 to 4. As a consequence, the Magnograph manufacturer modified the results given by Eq. 4 with the following 'peak estimator':

$$Peak\ Corrected\ LBS\ =\ Value\ from\ Eq.\ 4 \times \frac{(Peak\ Value \times 0.225 + 0.55)}{Average\ Value} \qquad Eq.\ 5$$

The variance associated with Eq. 5 was found to be somewhat high.

(C) Best-fit empirical models — stranded ropes

The results obtained with the 'best fit' strength-loss models tended to follow the form of Equations 1 to 4 up to rope sizes of about $1\frac{1}{2}$ in. For rope sizes in excess of $1\frac{3}{4}$ in., 'best fit' models of quite a different type were required. The basic models for stranded hoist ropes were found to be as follows:

Typical LF Values, or LBS Values:

LF = 0.13× (LMA + 1) Volts — for insert sizes A and B

LF = 0.23 × (LMA) + 0.13 Volts — for insert size C

$LBS = 0.33 \times (LF_{average}) \times (LMA)^{0.8} + 0.91\ (LF_{average})$ — for insert size D

$LBS = 1.4 \times (LF_{average}) - 2.9$ — for insert size E

where the LMA value is to be inserted in %, and the $LF_{average}$ in Volts.

The foregoing models are referenced upon a standardized LF sensitivity, and upon an LF control-gain of 1.0 abs.

Fewer data points were available for developing the models to fit inserts D and E, than were available for inserts A, B, and C, respectively.

(D) Results for stranded ropes

The aforementioned models were developed by the Magnograph's manufacturer over a period of some $2\frac{1}{2}$ years. The combined approach utilizing both LMA and quantified LF level values to estimate LBS data are said to have produced noteable improvements in accuracy compared with the LBS estimates based on LMA measurements alone. In particular this is said to have been the case with samples showing strength-losses in excess of 10%.

The manufacturer stated that the error analysis of special tests showed an average error of about 0.5% with a standard deviation of 3.0 to 4.0%. The 95% confidence interval for the mean was also quoted by the manufacturer at ±3.0 to 4.0%.

(E) Other rope constructions

Tests by the manufacturer also included some locked-coil ropes, but none of spin-resistant construction. On reviewing results, the manufacturer commented: (1) upon the tendency of locked-coil (LC) ropes not to develop internal corrosion in the same manner as stranded ropes, and (2) upon the tendency of LC ropes to exhibit sizeable increases (sometimes as much as 10%) in strength due to work hardening. The latter phenomenon can not be measured with EM rope testers; this makes modelling of LBS for LC ropes a more difficult proposition than it is for stranded ropes. Consequently, more data are required in the LC case, to reduce the variance of the results.

(F) Best-fit empirical models — LC ropes

Typical LF Values:

LF = 0.08 × (LMA) + 0.11 Volts — for insert size B

LF = 0.13 × (LMA) + 0.11 Volts — for insert size C

where the LMA value is to be inserted in %.

These models are again referenced upon a standard LF sensitivity, and upon an LF control-gain of 1.0 abs.

As before, the estimation process described by Equations 1 to 5 was used, together with the typical levels calculated above, to evaluate the results of a number of special tests.

(G) Operational examples

We attach copies (Appendix 3) of a few (of the many) operational examples that were reported to CANMET by the Magnograph operator in the course of the R&D project previously referred to.

SUMMARY

In this report we discussed three important, yet little known, aspects of non-destructive wire-rope testing with EM instruments.

Firstly, we described, in some detail, the procedure to be followed in order to obtain a rope's percentage loss-of-metallic-area relative to its original, 'as manufactured', dimensions (LMA_{total}) — rather than relative to some 'best' rope location (LMA) which, itself, may have lost much of its original load-bearing metallic mass. We illustrated the great practical importance of this procedure by demonstrating: (1) the serious pitfalls that may arise on comparing LMA chart-readings obtained with instrument calibrations at different rope-locations, and (2) the problems involved in legitimately aligning and splicing together strip-chart segments.

Secondly, we discussed a novel method to calibrate an EM instrument's LF signal, and briefly described the advantages in having such a calibrated, rather than the usual uncalibrated, LF trace.

Thirdly, we listed the methods used by the operators of the various EM instruments that were involved in CANMET's R&D project of current interest, to estimate LBS values on hand of the chart-readings. In particular, we discussed the method used by the Magnograph operator, and the efforts to utilize both the LF and the LMA instrument traces.

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APPENDIX 1

Determination of %LMA relative to the original rope metallic cross-sectional area by measurement of Total Metallic Rope Area (TMA), using a Magnograph tester — operational examples

EXAMPLE 'A'

Testing of our rope #1 (ref. 12), a 1.000 in. hoist-rope.

Rope constructional details

Original metallic cross-sectional area (A) = 0.4578 in^2 (assumed)

Original mass per unit length,
from manufacturers' catalogues, such as Figures 5 to 7 =

for 1.000 in., 18× 7 construction: 2.53 kg/m (Fig. 6a) to 2.64 kg/m (Fig. 6c)

for 1.000 in., 6× 27 construction: 2.48 kg/m (Fig. 5b) to 2.59 kg/m (Fig. $5a_1$)

Test details

Instrument used: serial #81-01 Magnograph, with insert 'B'.

Table 1

Test results (after ref. 12)

Test date	Test #	Test site	LMA-zero dial-reading*	kg/m at calibr. segment**	Instr. calibr. at†	LMA at pt. of calibr.†	$LMA^{\dagger}_{max}$
1988 09 09	88-433	in situ	178	2.08	skip-end	0.9%	4.5%
1989 04 04	89-286J	shop	182	2.14	skip-end	0.9%	5.5%

*: as reported

**: obtained from manufacturers' calibration curves

†: from ref. 12, Figures 1a and 1b, respectively

TMA determination

Assuming the original (i.e., 100%) linear rope density to have been 2.48 kg/m (per Fig. 5b), and noting that the kg/m calibration-curve's abscissa reading (for an LMA-zero setting of 182, and for a 'B' insert) is 2.14 kg/m (Table 1), the respective LMA_{total} at the skip rope-end is $[100 - 100 \times \frac{2.14}{2.48}] = 13.7\%$. In other words, the calibration rope-segment lost **13.7%** of its original metallic cross-sectional area.

However, the calibration-segment was subsequently seen to itself have an LMA of 0.9% relative to the rope's 'best' segment, i.e., relative to the strip-chart's 100% reference-level. Consequently, at the 'best' rope segment the linear rope-density was $2.14 \times \frac{1}{1-\frac{0.9}{100}} = 2.159$ kg/m. This translates into a total metallic-area-loss, relative to the original rope metallic cross-sectional area (LMA_{total}) of $100[1 - \frac{2.159}{2.48}] = \mathbf{12.9\%}$.

Another critical rope-segment is the one where the rope has lost the maximum of its original metallic cross-sectional-area, i.e., where the NDT measurement established the LMA_{max} to be. For the shop-floor test in question the LMA_{max} chart-reading was 5.5% (Table 1), relative to the 100% reference chart-level, i.e., 5.5% – 0.9% = 4.6% relative to the calibration segment. Consequently, the linear rope-density at the critical rope-segment was $2.14[1 - \frac{4.6}{100}] = 2.042$ kg/m. This translates in an LMA_{total} of $100[1 - \frac{2.042}{2.48}] = \mathbf{17.7\%}$.

Remarks

Unfortunately, we were unable to obtain copies of the original rope documentation. In part, therefore, our calculations are based on assumed data. For this reason we illustrated the LMA_{total} calculation process for the shop-floor test-data only. With the 2.08 kg/m rope density at the calibration segment the in situ results would, in any case, be unacceptably different from the shop-floor ones.

EXAMPLE 'B'

Testing of our rope #7 (ref. 11), a $1\frac{1}{2}$ in. hoist-rope of 6 × 30, F.S., construction.

Rope constructional details

Original metallic cross-sectional area (A) = 1.0344 in^2 (assumed)

Original mass per unit length = 5.88 kg/m

Test details

Instrument used: serial #81-01 Magnograph, with insert 'C'.

Table 2

Test results (after ref. 11)

Test date	Test #	Test site	LMA-zero dial-reading*	kg/m at calibr. segment**	Instr. calibr. at†	LMA at pt. of calibr.†	$LMA^{\dagger}_{max}$
1988 08 23	88-383B	in situ	422	5.31	skip-end	3.9%	9.1%
1989 01 18	89-045	shop	397	5.00	drum-end	0.0%	10.7%
1989 04 04	89-286D	shop	434	5.46	skip-end	6.8%	14.5%

*: as reported

**: obtained from manufacturers' calibration curves

†: from ref. 11, Figures $1d_1$; 1e; and 1f, respectively

TMA determination

Using the manufacturer's calibration-curves, and noting the LMA-zero dial readings (Table 2) of 422; 397; and 434, we obtain rope-densities of 5.31 kg/m; 5.00 kg/m; and 5.46 kg/m. respectively, for the different rope-segments along which the Magnograph was calibrated. The original rope density was 5.88 kg/m. Therefore, the foregoing three rope densities — at the rope calibration segments — translate into LMA_{total} values of: 9.7%; 15.0%; and 7.1%, respectively.

At the critical rope-segments the LMA chart-readings (Table 2) were: 9.1% (in situ test); 10.7% (first shop-floor test); and 14.5% (second shop-floor test). While these values are, perhaps, reasonably close together, it appears that the LMA-zero dial settings for the two shop-floor tests must have been interchanged. We see no other explanation for having a lower LMA-zero setting (i.e., greater rope wear) reported at the 'best' rope-end (i.e., at the drum-end) than at the poorer skip rope-end.

Adjusting for this discrepancy, we obtain the following LMA_{total} values at the critical rope segments:

(a) for the in situ test of 1988 08 23:

— linear rope density at the calibration segment: 5.31 kg/m;

— linear rope density at the critical segment:

$$5.31[1 - \tfrac{(9.1-3.9)}{100}] = 5.03 \text{ kg/m}$$

— hence, $\text{LMA}_{total} = 100[1 - \tfrac{5.03}{5.88}] = \mathbf{14.4\%}$

(b) for the shop-floor test of 1989 01 18:

— linear rope density at the calibration segment: 5.46 kg/m;

— linear rope density at the critical segment:

$$5.46[1 - \tfrac{10.7}{100}] = 4.88 \text{ kg/m}$$

— hence, $\text{LMA}_{total} = 100[1 - \tfrac{4.88}{5.88}] = \mathbf{17.1\%}$

(c) for the shop-floor test of 1989 04 04:

— linear rope density at the calibration segment: 5.00 kg/m;

— linear rope density at the critical segment:

$$5.00[1 - \tfrac{(14.5-6.8)}{100}] = 4.62 \text{ kg/m}$$

— hence, $\text{LMA}_{total} = 100[1 - \tfrac{4.62}{5.88}] = \mathbf{21.5\%}$

Considering now the LMA_{total} at the 'best' rope segments, we note that of the three tests only one (the first shop-floor) was conducted with rope calibration at the 'best' drum rope-end. Here the rope had lost 7.1% of its original metallic cross-sectional area. On the other two test occasions conditions at the 'best' rope segments were as follows:

(1) in situ test on 1988 08 23:

$$5.31 \times \tfrac{1}{1-\frac{5.8}{100}} = 5.53 \text{ kg/m}$$

hence, $\text{LMA}_{total} = 100[1 - \tfrac{5.53}{5.88}] = \mathbf{6.0\%}$

(2) second shop-floor test on 1989 04 04:

$$5.00 \times \tfrac{1}{1-\frac{6.8}{100}} = 5.36 \text{ kg/m}$$

hence, $\text{LMA}_{total} = 100[1 - \tfrac{5.36}{5.88}] = \mathbf{8.8\%}$

Remarks

On comparing the in situ and shop-floor strip-charts (Figures $1d_1$; 1e; and 1f of ref. 11) we noted that in situ some 840 to 940 ft of rope-length at the drum-end was not tested. As a consequence the 'best' rope segment in the field had, itself, a 1.0% LMA relative to the 'best' segment on the shop-floor. This, however, has no effect on our calculations of the in situ LMA_{total} because these are based on calibration segments at the skip rope-end.

The three LMA_{total} values of 6.0%; 7.1%; and 8.8% at the 'best' rope segments are, under the circumstances, acceptably close together.

It is interesting to note that if, at the critical rope segments, we were to use a rough-and-ready (fast but inaccurate) calculation, by taking into account the %LMA chart-readings here plus the respective LMA_{total} values at the 'best' segments, we would obtain $9.1\% + 6.0\% = 15.1\%$; $10.7\% + 7.1\% = 17.8\%$; and $14.5\% + 8.8\% = 23.3\%$, rather than the 'true' values of 14.4%; 17.1%; and 21.5%.

EXAMPLE 'C'

Testing of our rope #4 (ref. 6), a $1\frac{1}{4}$ in. hoist-rope of 1 × 148, FLC, construction.

Rope constructional details

Original metallic cross-sectional area (A) = 1.0887 in^2 (assumed)

Original mass per unit length = 5.93 kg/m

Test details

Instrument used: serial #81-01 Magnograph, with insert 'C'.

Table 3

Test results (after ref. 6)

Test date	Test #	Test site	LMA-zero dial-reading*	kg/m at calibr. segment**	Instr. calibr. at†	LMA at pt. of calibr.†	$LMA^{\dagger}_{max}$
1988 10 19	88-525A	in situ	397	5.18	south -skip	2.8%	6.5%
1989 04 04	89-286G	shop	421	5.48	south -skip	7.0%	11.5%

*: as reported

**: obtained from manufacturers' calibration curves

†: from ref. 6, Figures 3a and 9a, respectively

TMA determination

Using the manufacturer's calibration-curves, and noting the LMA-zero dial readings (Table 3) of 397 and 421, we obtain rope-densities of 5.18 kg/m (in situ test) and 5.48 kg/m (shop-floor test) for the rope-segments along which the Magnograph was calibrated. The original rope density was 5.93 kg/m. Therefore, the foregoing two rope densities — at the rope calibration segments — translate into LMA_{total} values of: 12.7% (in situ test) and 7.6% (shop-floor test), respectively.

Neither of the foregoing calibrations were undertaken along the 'best' rope segment. In fact, the %LMA chart-readings at the calibration segments were 2.8% (in situ) and 7.0% (shop-floor).

Consequently, at the 'best' rope segments the LMA_{total} values were as follows:

(1) for the in situ test of 1988 10 19:

$$5.18 \times \frac{1}{1-\frac{2.8}{100}} = 5.33 \text{ kg/m}$$

hence, $LMA_{total} = 100[1 - \frac{5.33}{5.93}] = \mathbf{10.1\%}$

(2) shop-floor test of 1989 04 04:

$$5.48 \times \frac{1}{1-\frac{7.0}{100}} = 5.89 \text{ kg/m}$$

hence, $LMA_{total} = 100[1 - \frac{5.89}{5.93}] = \mathbf{0.6\%}$

Similarly, at the critical rope segments the LMA_{total} values are:

(1) in situ:

— linear rope density at the calibration segment: 5.18 kg/m;

— linear rope density at the critical segment:

$$5.18[1 - \frac{(6.5-2.8)}{100}] = 4.99 \text{ kg/m}$$

— hence, $LMA_{total} = 100[1 - \frac{4.99}{5.93}] = \mathbf{15.9\%}$

(2) shop-floor:

— linear rope density at the calibration segment: 5.48 kg/m;

— linear rope density at the critical segment:

$$5.48[1 - \frac{(11.5-7.0)}{100}] = 5.23 \text{ kg/m}$$

— hence, $LMA_{total} = 100[1 - \frac{5.23}{5.93}] = \mathbf{11.7\%}$

Remarks

As is the case in Example 'B', the foregoing LMA_{total} results, especially at the 'best' rope segments, are unacceptably wide apart. Since the rope was calibrated at the same (i.e., the South-skip) end both in situ and on the shop-floor, the 6.0% difference between the two LMA-zero dial readings (Table 3) is questionable. This situation is then further compounded by the various problems detailed in reference 6. This results, inter alia, in the unacceptable difference of some 150% between the two %LMA chart-readings obtained at one and the same rope-end (where the Magnograph was calibrated both in situ and on the shop-floor).

A human error is suspected.

EXAMPLE 'D'

Testing of our rope #5 (ref. 8), a $1\frac{7}{16}$ in. hoist-rope of 1 × 176, FLC, construction.

Rope constructional details

Original metallic cross-sectional area (A) = 1.2887 in^2 (assumed)

Original mass per unit length = 7.22 kg/m

Test details

Instrument used: serial #81-01 Magnograph, with insert 'C'.

Table 4

Test results (after ref. 8)

Test date	Test #	Test site	LMA-zero dial-reading*	kg/m at calibr. segment**	Instr. calibr. at†	LMA at pt. of calibr.†	$LMA^{\dagger}_{max}$
1988 10 19	88-525B	in situ	480	6.25	skip-end	2.7%	9.0%
1989 04 04	89-286F	shop	532	6.93	skip-end	2.9%	11.0%

*: as reported

**: obtained from manufacturers' calibration curves

†: from ref. 8, Figures 3b and 7, respectively

TMA determination

Using the manufacturer's calibration-curves, and noting the LMA-zero dial readings (Table 4) of 480 and 532, we obtain rope-densities of 6.25 kg/m (in situ test) and 6.93 kg/m (shop-floor test) for the rope-segments along which the Magnograph was calibrated. The original rope density was 7.22 kg/m. Therefore, the foregoing two rope densities — at the rope calibration segments — translate into LMA_{total} values of: 13.4% (in situ test) and 4.0% (shop-floor test), respectively.

Neither of the foregoing calibrations were, however, undertaken along the 'best' rope segment. In fact, the %LMA chart-readings at the calibration segments were 2.7% (in situ) and 2.9% (shop-floor).

Consequently, at the 'best' rope segments the LMA_{total} values were as follows:

(1) for the in situ test of 1988 10 19:

$$6.25 \times \frac{1}{1-\frac{2.7}{100}} = 6.42 \text{ kg/m}$$

hence, $\text{LMA}_{total} = 100[1 - \frac{6.42}{7.22}] = \mathbf{11.0\%}$

(2) shop-floor test of 1989 04 04:

$$6.93 \times \frac{1}{1-\frac{2.9}{100}} = 7.14 \text{ kg/m}$$

hence, $\text{LMA}_{total} = 100[1 - \frac{7.14}{7.22}] = \mathbf{1.1\%}$

Similarly, at the <u>critical</u> rope segments the LMA_{total} values are:

(1) in situ:

— linear rope density at the calibration segment: 6.25 kg/m;

— linear rope density at the critical segment:

$$6.25[1 - \frac{(9.0-2.7)}{100}] = 5.86 \text{ kg/m}$$

— hence, $\text{LMA}_{total} = 100[1 - \frac{5.86}{7.22}] = \mathbf{18.9\%}$

(2) shop-floor:

— linear rope density at the calibration segment: 6.93 kg/m;

— linear rope density at the critical segment:

$$6.93[1 - \frac{(11.0-2.9)}{100}] = 6.37 \text{ kg/m}$$

— hence, $\text{LMA}_{total} = 100[1 - \frac{6.37}{7.22}] = \mathbf{11.8\%}$

<u>Remarks</u>

As is the case in Example 'C', the foregoing LMA_{total} results, especially at the 'best' rope segments, are unacceptably wide apart. Since the rope was calibrated at the same end both in situ and on the shop-floor, the 11.0% difference between the two LMA-zero dial readings (Table 4) is questionable. This situation then translates into the major (some 300%) difference between the TMA losses of 13.4% and 4.0% at the rope calibration segments, and is finally compounded into the completely disparate LMA_{total} values of 11.0% and 1.1% at the 'best' rope segments.

A human error is suspected.

APPENDIX 2

Erroneous comparison of disparate test-results —

LMA chart-reading adjustments in case of multiple

EM instrument calibrations along the same wire-rope

In this Appendix 2 we examine the situations that arise:

(1) with a single test set-up along the rope, but with consecutive tests that are many months apart. In this case: (a) the rope segment, along which the EM instrument is currently being calibrated, may have seriously deteriorated between one routine test and the next one, or (b) the previously used calibration-segment may not be readily available for calibration purposes the next time round;

(2) with double test set-ups along the rope, which often involve greatly differing calibration-segments, even in case of same-day tests.

Situation (1) — single test set-up along rope

(I) — Theoretical considerations

We assume a uniform linear rope-density of 11.0 kg/m along the entire 'as manufactured' rope. After, say, one year of operational service (stage 1) we assume general rope-conditions of the type encountered, for example, in case of our rope #5 (see Fig. 1 of ref. 8). Specifically, the rope is assumed to have lost 2 kg/m of its original mass/m at point 'A'; 3 kg/m at 'B'; and 1 kg/m at 'C'. In other words the shape of the EM instrument's LMA trace will be as sketched in Fig. 8. However, in quantitative terms, the %LMA chart-readings will depend on where, along the rope, the EM tester happened to be calibrated — except at the 'best' rope section 'C', where we always have 0.0% LMA, in any case.

As an example, at 'A' the LMA chart-readings will be:

$\frac{1}{9} \times 100 = 11.1\%$, if we calibrated at 'A', and $\frac{1}{10} \times 100 = 10.0\%$, if we calibrated at 'C'.

Similarly, at 'B' the respective LMA readings will be:

$\frac{2}{9} \times 100 = 22.2\%$, if we calibrated at 'A', and $\frac{2}{10} \times 100 = 20.0\%$, if we calibrated at 'C'.

After a second year of operational use (stage 2), we assume that the rope has further deteriorated at 'A' — say, to 8.5 kg/m — while , for one reason or another, little or no changes occurred at 'B' (8 kg/m) and at 'C' (10 kg/m). The LMA chart-readings will, therefore, now be as follows:

at 'C': 0.0%, as before, no matter where along the rope the EM instrument was calibrated;

at 'A': $\frac{1.5}{8.5} \times 100 = 17.6\%$, if we calibrated at 'A', and $\frac{1.5}{10} \times 100 = 15.0\%$, if we calibrated at 'C';

at 'B': $\frac{2}{8.5} \times 100 = 23.5\%$, if we calibrated at 'A', and $\frac{2}{10} \times 100 = 20.0\%$, if we calibrated at 'C'.

Finally, after a third year in operation (stage 3), we assume that the linear rope densities have now decreased to: 8 kg/m at 'A'; 7.0 kg/m at 'B'; and 9.0 kg/m at 'C'. The LMA chart-readings will, therefore, be:

at 'C': 0.0%, as before, no matter where along the rope the EM instrument was calibrated;

at 'A': $\frac{1}{8} \times 100 = 12.5\%$, if we calibrated at 'A', and $\frac{1}{9} \times 100 = 11.1\%$, if we calibrated at 'C';

at 'B': $\frac{2}{8} \times 100 = 25.0\%$, if we calibrated at 'A', and $\frac{2}{9} \times 100 = 22.2\%$, if we calibrated at 'C'.

We tabulated the foregoing results in Table 5, and illustrated them in Fig. 8.

Obviously, a straightforward comparison of the results in Table 5 is misleading. The situation at 'A' is particularly confusing, where 17.6% was recorded during stage 2, and 12.5% a year later (stage 3), provided the EM instrument was calibrated at 'A' on both occasions.

To remedy this situation, and to provide a legitimate basis for comparisons, an unchanging reference-base must be used, and not, as often happens, a reference-base that shifts from one test to the next.

Perhaps the best, and most logical, way to avoid the above noted problems is to convert all %LMA chart-readings to $\%LMA_{total}$ values. The necessary process for doing this has been described in Appendix 1. As shown there, LMA_{total} values at the calibration rope-segments are obtained by using the manufacturer's calibration-curves. At all other points the LMA_{total} values are obtained by using both the manufacturer's calibration curves and the strip-chart readings. Examples of the foregoing procedure are given in the following:

(1) LMA_{total} at 'A', stage 1, if calibration was at 'C', is 18.2%, because $[10 - \frac{10}{100} \times 10] = 9$ kg/m (at 'A'), and $\frac{(11-9)}{11} \times 100 = 18.2\%$;

(2) LMA_{total} at 'A', stage 3, if calibration was at 'C', is 27.3%, because $[9 - \frac{11.1}{100} \times 9] = 8.001$ kg/m, and $\frac{(11-8.001)}{11} \times 100 = 27.3\%$;

(3) LMA_{total} at 'A', stage 3, if calibration was at 'A', is 27.3%, because $[9 - \frac{12.5}{100} \times 8] = 8$ kg/m, and $\frac{(11-8)}{11} \times 100 = 27.3\%$;

(4) LMA_{total} at 'B', stage 1, if calibration was at 'A', is 27.3%, because $[10 - \frac{22.2}{100} \times 9] = 8$ kg/m, and $\frac{(11-8)}{11} \times 100 = 27.3\%$;

(5) LMA_{total} at 'B', stage 2, if calibration was at 'A', is 27.3%, because $[10 - \frac{23.5}{100} \times 8.5] = 8$ kg/m, and $\frac{(11-8)}{11} \times 100 = 27.3\%$;

(6) LMA_{total} at 'B', stage 3, if calibration was at 'A', is 36.4%, because $[9 - \frac{25.0}{100} \times 8] = 7$ kg/m, and $\frac{(11-7)}{11} \times 100 = 36.4\%$;

(7) LMA_{total} at 'B', stage 3, if calibration was at 'C', is 36.4%, because $9 \times \frac{22.2}{100} = 2$ kg/m, $[9 - 2] = 7$ kg/m, and $\frac{(11-7)}{11} \times 100 = 36.4\%$;

(8) LMA_{total} at 'C', stage 1, if calibration was at 'A', is 9.09%, because $[9 + \frac{11.1^*}{100} \times 9] = 10$ kg/m, and $\frac{(11-10)}{11} \times 100 = 9.09\%$;

(9) LMA_{total} at 'C', stage 2, if calibration was at 'A', is 9.09%, because $[8.5 + \frac{17.6^*}{100} \times 8.5] = 10$ kg/m, and $[1 - \frac{10}{11}] \times 100 = 9.09\%$;

(10) LMA_{total} at 'C', stage 3, if calibration was at 'A', is 18.2%, because $[8 + \frac{12.5^*}{100} \times 8] = 9$ kg/m, and $[1 - \frac{9}{11}] \times 100 = 18.2\%$;

We tabulated the respective $\%LMA_{total}$ values for rope segments 'A'; 'B'; and 'C' — in each case for stages 1; 2; and 3 — in Table 5, and illustrated them in Fig. 8.

(II) — <u>An operational example</u>

An interesting operational example was discussed in reference 16. The rope in question, designated by the mine as rope #46, was the companion rope of rope #47. The latter failed two days after its final EM testing with a Rotesco AC instrument,

*: these values are LMA chart-readings at point 'A', respectively at stages 1, 2, and 3, with calibration at 'A'

when the LBS_{max} was reported to be 9.0%. These ropes were of $1\frac{1}{2}$ in., 6×27, flattened strand, preformed, right Lang lay, nylon core, galvanized construction, with a breaking strength of 258,250 lb (#46) and 256,750 lb (#47). Their original linear density was 4.09 lb/ft.

After the failure of rope #47 its companion rope (#46) was tested reel-to-reel, with a single instrument set-up, on 1990 07 05 (test # MG3). We reproduce (Fig. 9b) the resultant strip-chart. We also reproduce (Fig. 9a) the final Rotesco AC in-situ strip-chart, obtained on 1990 06 21 (test #AM-118). A comparison of these charts illustrates the point made previously elsewhere (11), namely the legitimacy of comparing in-situ and reel-to-reel tests.

It will be noted that in case of Fig. 9b one instrument set-up was used, with calibration at the skip-end of the rope, while in Fig. 9a two instrument set-ups, and two instrument calibrations were used. It will also be noted (Table 6) that the destructively obtained 'true' LBS at the skip rope-end was 12.0%. Consequently, the reel-to-reel %LMA chart-readings with the Rotesco AC instrument (see Table 3 of ref. 16) at sample position numbers 1 through 10 (as marked on Fig. 9b) must all be adjusted to reflect the deteriorated condition of the rope segment along which the instrument was calibrated. Only by converting the %LMA chart-readings into 'total' %LMA (i.e., LMA_{total}) values can the destructively obtained 'true' LBS values, and the non-destructively obtained 'estimated' ones, be compared legitimately. The $\%LMA_{total}$ values at the sample positions 1 through 10 (with the respective %LMA chart-readings in brackets) are as follows: 10.5% (0.0%); 10.5% (0.0%); 13.1% (3.0%); 14.0% (4.0%); 13.5% (3.4%); 14.2% (4.2%); 13.1% (3.0%); 13.3% (3.2%); 13.5% (3.4%); and 12.0% (1.7%).

Consequently, on using the same %LMA to %LBS proportionality constant of 1.77, as had been used previously (see ref. 16), we now obtain the following estimated %LBS values at the respective sample positions 1 through 10: 18.6%; 18.6%; 23.2%; 24.8%; 23.9%; 25.1%; 23.2%; 23.5%; 23.9%; and 21.2%. Interestingly, CANMET's corresponding LBS_{max} estimate was 18.1%, while that of the Ontario MOL was 19.0%, respectively 23.6% (see ref. 16).

Table 5

Comparison of %LMA and %LMA$_{total}$ results

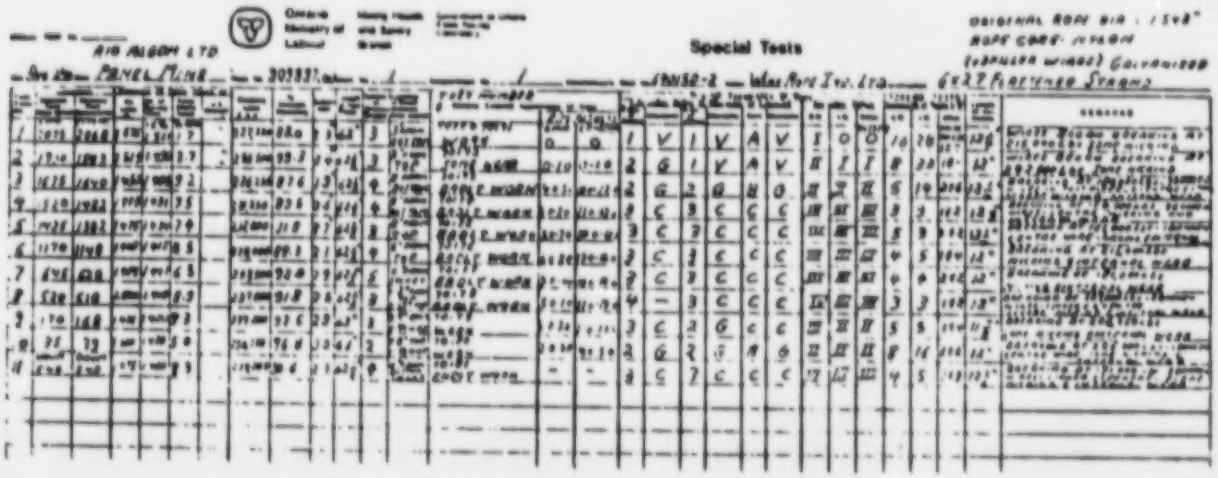
Results at point	Results at stage	With calibr. at	LMA readings*	LMA$_{total}$ values †
'A'	1	'A'	11.1%	18.2%
		'C'	10.0%	18.2%
	2	'A'	17.6%	22.7%
		'C'	15.0%	22.7%
	3	'A'	12.5%	27.3%
		'C'	11.1%	27.3%
'B'	1	'A'	22.2%	27.3%
		'C'	20.0%	27.3%
	2	'A'	23.5%	27.3%
		'C'	20.0%	27.3%
	3	'A'	25.0%	36.4%
		'C'	22.2%	36.4%
'C'	1	'A'	0.0%	9.09%
		'C'	0.0%	9.09%
	2	'A'	0.0%	9.09%
		'C'	0.0%	9.09%
	3	'A'	0.0%	18.2%
		'C'	0.0%	18.2%

*: per respective strip-charts

†: per respective strip- and calibration-charts

Table 6

Ontario MOL special tests: Rio Algom rope #46 samples



Situation (2) — double test set-up along rope

Contrary to the previously discussed situation (1), we now investigate same-day test events obtained with a repeated test set-up along the same rope.

As has been stated before in this report, and elsewhere (e.g., in ref. 3 and 12), in case of double test set-ups strip-chart evaluation is greatly facilitated by temporarily taping a 'calibration wire', of known metallic cross-sectional area, to the overlapping rope-segment. Unfortunately, this seems to be more of an exception than the rule, judging by the reports received during CANMET's research project. Moreover, operators of the different EM instruments also differed in other matters, such as: (1) whether, or not, they recalibrated their tester after moving from the original to another rope-section, and (2) whether, or not, they altered their LMA sensitivity setting after relocating their instrument.

Case (1) — We suggest that, if at all possible, the individual strip-chart segments obtained during a double test set-up be run with one and the same instrument sensitivity and calibration settings — whether by being able to maintain the original calibration while moving the sensor-head, or by recalibrating the second time along the identical segment in the overlapping rope-section. Moreover, to avoid problems such as the one discussed in ref. 10, care must be taken to correctly reposition the sensor-head's polarity when relocating it. If, in addition, a 'calibration wire' has been placed, the individual chart-segments can quite easily be spliced together at the latter wire's location, which is conspicuous on both the LMA and LF chart-traces (e.g., see Figures 10a and 10b, after Fig. 2a of ref. 12). A single 100% reference level can then be chosen for the entire spliced chart.

In case of a single calibration and sensitivity setting it may, even, be a relatively simple matter to locate obvious characteristic "fingerprints" — on either the LMA or LF chart-traces of the overlapping rope section — that are present due to operational conditions, without a 'calibration wire' having been placed. These, together with the distance markings along the strip-chart edge, will enable the operator to correctly splice together the chart-segments. However, such operational "fingerprints" may, or may not, be present, and even if available, the process will take more time and effort than locating a calibration wire's "fingerprint".

The foregoing splicing process remains a relatively simple procedure — as long as a single instrument calibration and a 'calibration wire' were used — even if the sensitivity settings of the two strip-chart segments differ. In this case, though, there will be a

break in the 100% reference level along the chart, at the point where the sensitivity settings change (e.g., see Fig. 11, after Fig. 4 of ref. 6). In the absence of a 'calibration wire' operational "fingerprints", and distance markings along the strip-chart, need to be observed.

Case (2) — The splicing process becomes much more complicated should different instrument calibrations have been used along the two individual rope sections. This is so even if: (a) the correct point for chart splicing is easy to locate, and (b) if identical LMA sensitivity settings are used for both chart-sections — an operational condition, for example, when using the Magnograph with its standard calibration chart (Fig. 3). We illustrate this case (2) situation in Fig. 12. Here the overall shape of the LMA trace is that of our rope #4 (see ref. 6). We use this operational case to illustrate our discussions because it involves a rather unusual occurrence: in the field the rope was tested along its entirety with a single test set-up (Fig. 12a); however, on the shop-floor two set-ups could not be avoided (Fig. 12b). However, instead of using the actually obtained LMA chart-readings, we base our illustration on the following hypothetical linear rope density values: (1) 11.0 kg/m along the entire 'as manufactured' rope-length, and (2) 7.0 kg/m at 'A'; 8.5 kg/m at 'B'; 8.0 kg/m at 'C'; 10.0 kg/m at 'D'; and 9.0 kg/m at 'E'. Instrument calibrations are assumed to have occurred as in actuality, namely: at rope-end 'E' in situ, and, on the shop-floor, at 'C_1' for rope section 'A' to 'C_1', and at 'E' for the remaining section 'C_2' to 'E'. Consequently, the LMA chart-readings were as follows (Fig. 12):

In situ:

at 'A': $\frac{(10-7)}{9} \times 100 = 33.3\%$

at 'B': $\frac{(10-8.5)}{9} \times 100 = 16.7\%$

at 'C': $\frac{(10-8)}{9} \times 100 = 22.2\%$

at 'D': 0.0%

at 'E': $\frac{(10-9)}{9} \times 100 = 11.1\%$

On the shop-floor:

at 'A': $\frac{(8.5-7)}{8} \times 100 = 18.8\%$

at 'B': 0.0%

at 'C_1': $\frac{(8.5-8)}{8} \times 100 = 6.3\%$

at 'C_2': $\frac{(10-8)}{9} \times 100 = 22.2\%$

at 'D': 0.0%

at 'E': $\frac{(10-9)}{9} \times 100 = 11.1\%$

We can not, however, simply splice the two chart-segments together at 'C_2', and then extend the 100% reference level of segment 'C_2' – 'E' along segment 'A' – 'C_1'. If we did so we would get the incorrect LMA chart-readings at 'A' and at 'B' of 34.7% and 15.9%, respectively, rather than the correct ones of 33.3% and 16.7%. The problem is that segments 'A' to 'C_1', and 'C_2' to 'E', were tested with two different instrument calibrations, viz., with one obtained at 'C_1' and the other at 'E'. Moreover, for one reason or another, it was not possible to test the entire rope-length with either one of these calibrations — as had been possible in case of the aforementioned situation (1). Consequently, we cannot normalize all chart-readings on the basis of a single calibration-base. It follows that the two individual chart segments can not — in this case — be legitimately spliced together, ass could be done with the case (1) strip chart segments. Correct splicing can only be done on hand of a single reference-base. The most logical base to choose is the rope's original 'as manufactured' linear density (11.0 kg/m in the present case), which is always uniform along the entire rope-length. On this basis we obtain the LMA_{total} values at all rope-segments, i.e., the metallic cross-sectional area losses with reference to the original rope conditions.

By using the manufacturer's instrument calibration curves and the relevant strip-chart sections, we obtain the following LMA_{total} (Fig. 12) values for case (2):

(1) with calibration at 'C_1'

at 'A': $LMA_{total} = \frac{11-8\times[1+\frac{8.3}{100}-\frac{16.6}{100}]}{11} \times 100 = 36.4\%$

at 'B': $LMA_{total} = \frac{11-8\times[1+\frac{8.3}{100}]}{11} \times 100 = 22.7\%$

at 'C_1': $LMA_{total} = \frac{(11-8)}{11} \times 100 = 27.3\%$

(2) with calibration at 'E'

at 'C_2': $LMA_{total} = \frac{11-9\times[1+\frac{11.1}{100}-\frac{22.2}{100}]}{11} \times 100 = 27.3\%$

at 'D': $LMA_{total} = \frac{11-9\times[1+\frac{11.1}{100}]}{11} \times 100 = 9.09\%$

at 'E': $LMA_{total} = \frac{(11-9)}{11} \times 100 = 18.2\%$

Note that since the common reference-base for both rope-sections is the rope's original linear density of 11.0 kg/m, the LMA_{total} is the same (27.3%) at 'C_1' and 'C_2',

whether the instrument was calibrated at 'C_1' or at 'E'. Also, the 100% reference level along the entire spliced chart can now be placed at 'D', i.e., at the 'best' rope-segment. It should be noted, however, that this level, itself, has a 9.09% LMA_{total}.

Case 3 — Finally, the unusual situation can arise when — for one reason or another — the two strip-chart segments do not contain a common, overlapping, rope-segment. Such was the case, for example, when shop-floor testing our operational rope #4 (ref. 6), because some 300 ft of the in situ rope had to be excised before reel-to-reel testing could proceed.

In cases like this there is, of course, no question of splicing the two chart-segments together, unless we happen to know — as was the case with our rope segments #4a and #4b — that the LMA in the missing, i.e., untested, rope section was negligible. In any case, by proceeding as in the foregoing cases (1) or (2), we can obtain consistent LMA results for the entire rope-length.

APPENDIX 3

Examples of Magnograph operator's LBS estimates

on our rope #7 (ref. 11)

For our rope #7 (ref. 11) the Magnograph operator submitted %LBS estimates for both the 1989 01 18, and the 1989 04 04 shop-floor tests.

In case of the former tests, these estimates (report #89-045) cover rope-sections at the 455, 521, 609, 722, and 844 yard locations from start of the test at the drum rope-end (i.e., at 453, 387, 299, 186, and 64 yards from the conveyance rope-end). The respective LBS estimates at these locations, together with the corresponding LMA chart-readings (in brackets), were: 16.2% (8.5%); 10.7% (7.5%); 8.3% (6.0%); 12.9% (7.5%); and 18.5% (11.0%). We attach copies of the operator's relevant report-sheets and strip-chart segments (Figures 13a to 13e). Destructive tests were performed at the conveyance rope-end, and at 78 yards and 262 yards from this end. Interestingly, the latter two LBS test results were 16.0% and 8.0% — assuming that the 4.0% LBS occurred at the rope-end — which compares favourably with the respective estimates of 18.5% (at 64 yards) and 8.3% (at 299 yards).

In case of the 1989 04 04 reel-to-reel shop-floor tests, the operator submitted LBS estimates (report #89-286D) for the 52.5, 58.0, 62.5, 68.5, and 81.0 yard rope-locations from the start of the test at the conveyance rope-end. Respective LBS estimates were: 20.7%, 24.2%, 25.5%, 23.0%, and 22.2%. We attach a copy of the relevant strip-chart segment (Fig. 14). However, we only reproduce a copy of one LBS report sheet, namely the one which is based on the measured rope conditions at the 81 yard segment; it is the only one close to any of the three segments (at 78, 256, and 908 yards) that were destructively tested. Interestingly, here the destructive test resulted in an LBS of 16.0%, while the corresponding estimates specify an LBS of 22.2% and 23.0%.

It need also be noted that the 'true' LBS values are obtained relative to the original rope-strength, while the 'estimated' ones are relative to a 'best' rope-section. In other words, the bases for comparison are not, necessarily, identical. Under these circumstances the differential between the 'true' and the 'estimated' %LBS values is acceptable.

APPENDIX 4

Figures 1 to 14

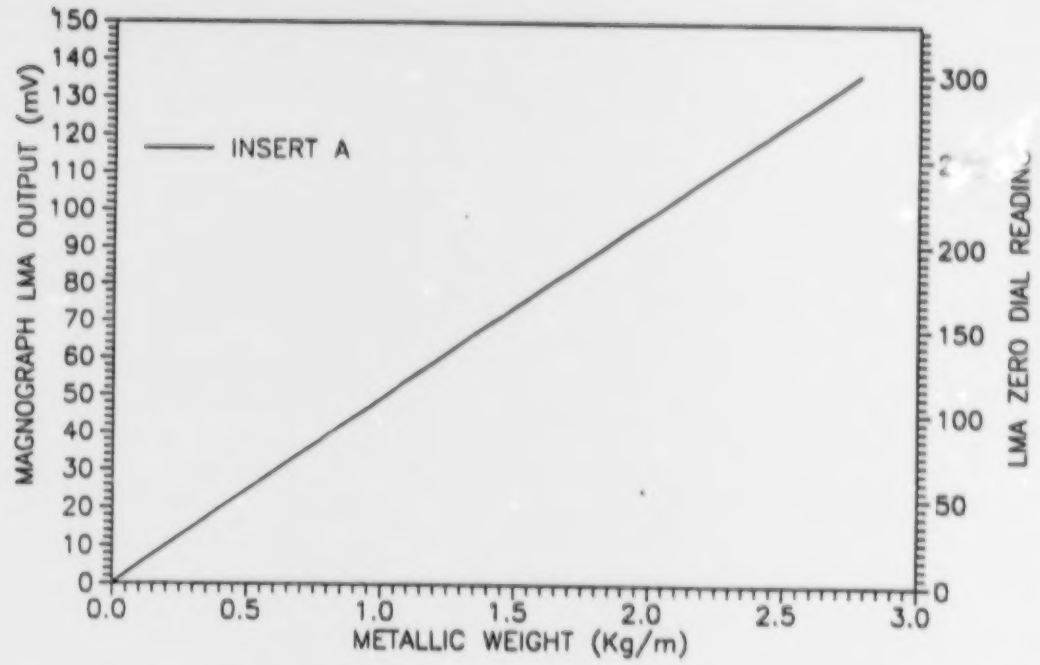


Fig. 1a — Magnograph with insert 'A'; LMA channel output (mV) vs metallic weight (kg/m)

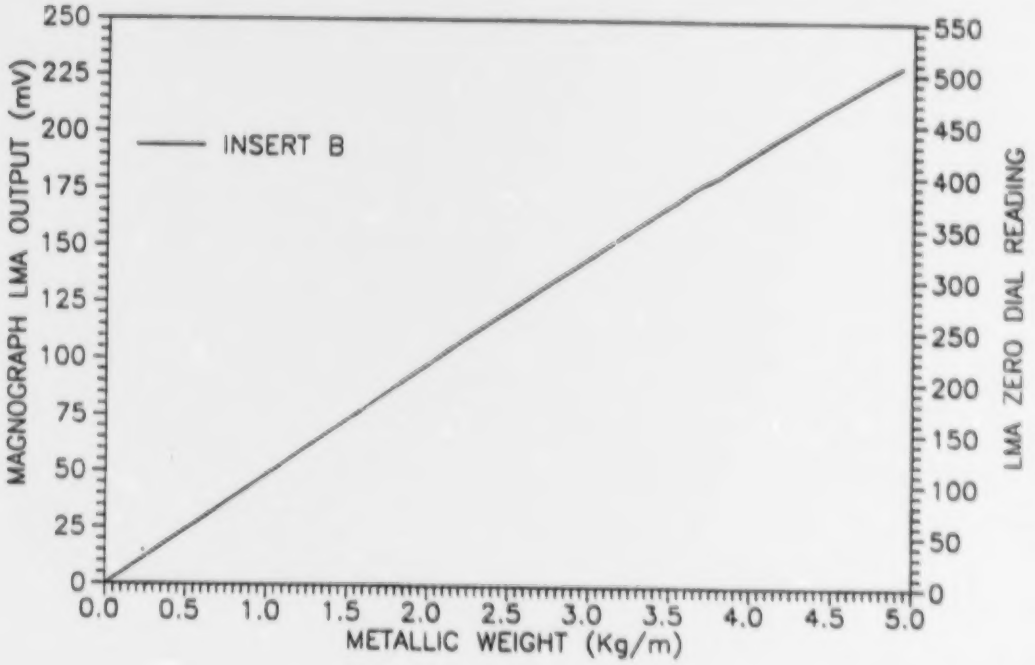


Fig. 1b — Magnograph with insert 'B'; LMA channel output (mV) vs metallic weight (kg/m)

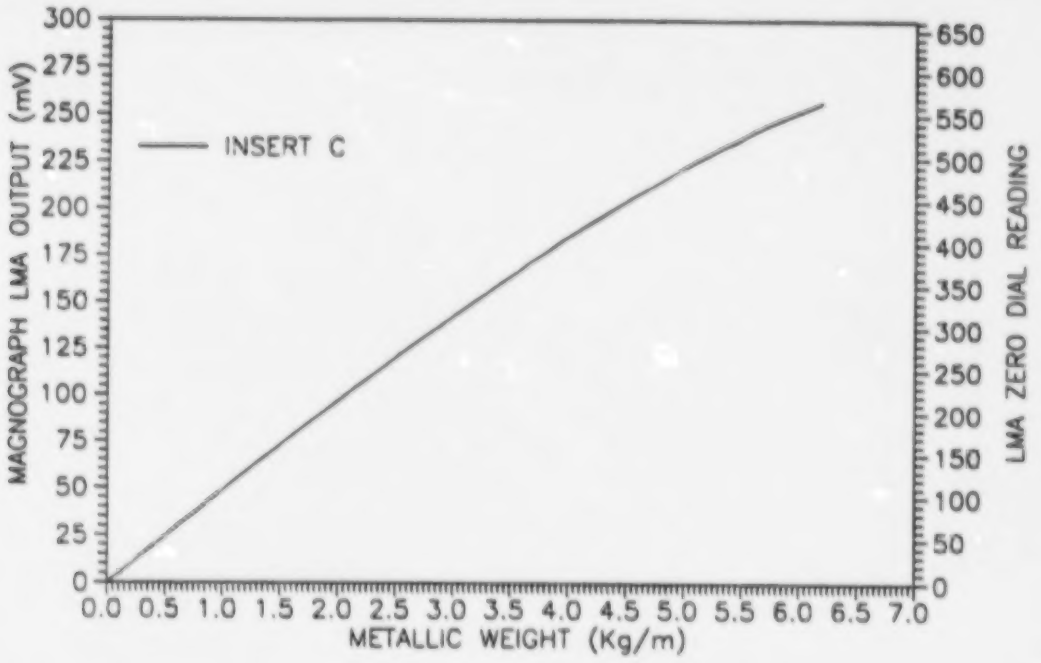


Fig. 1c — Magnograph with insert 'C'; LMA channel output (mV) vs metallic weight (kg/m)

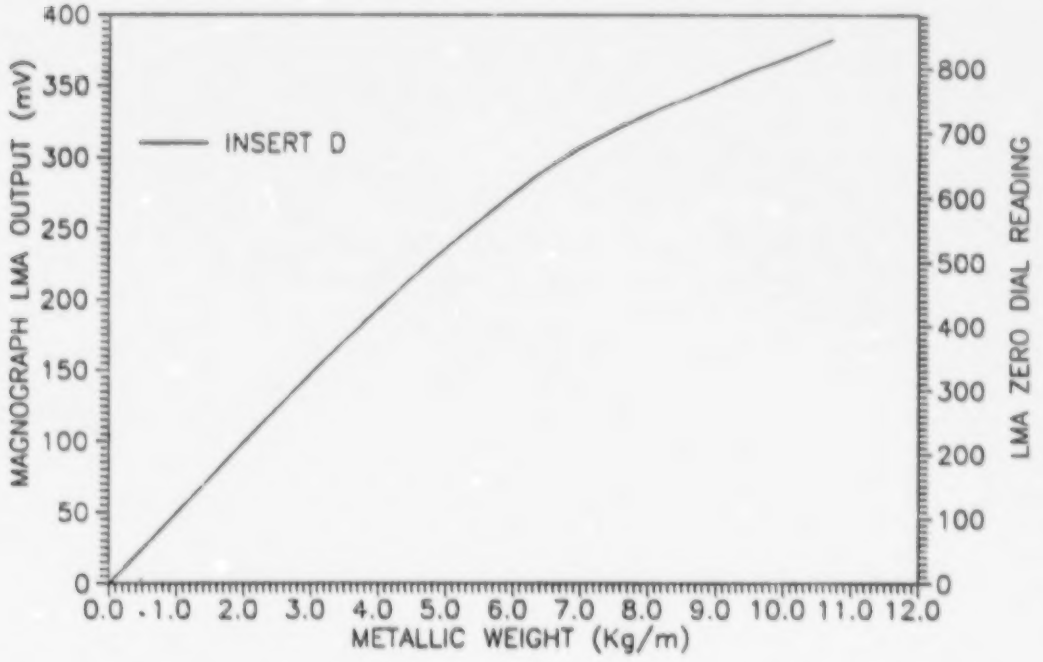


Fig. 1d — Magnograph with insert 'D'; LMA channel output (mV) vs metallic weight (kg/m)

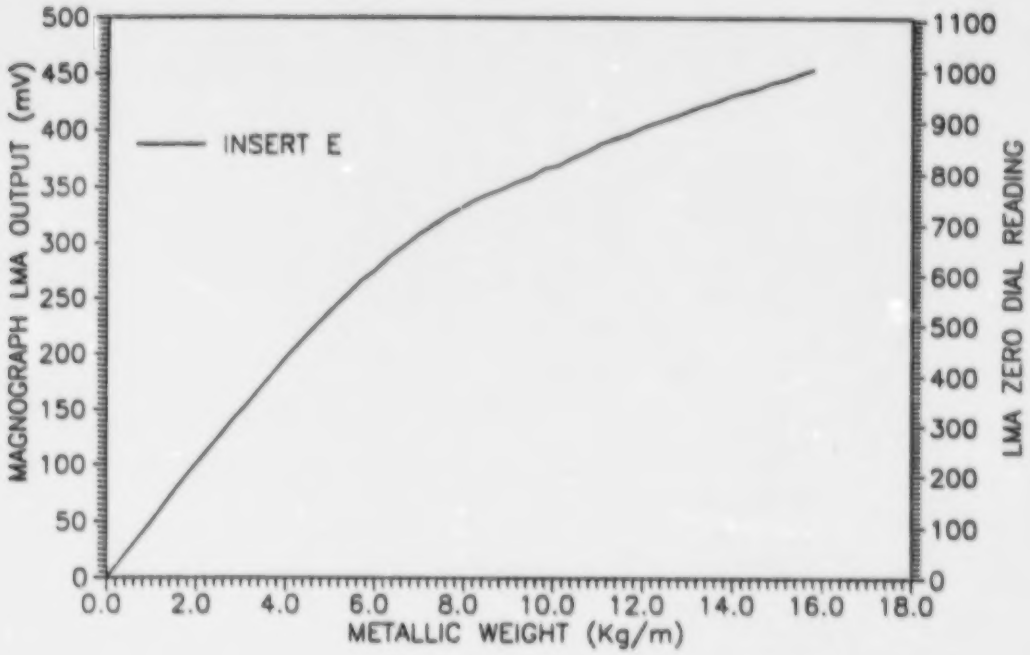


Fig. 1e — Magnograph with insert 'E'; LMA channel output (mV) vs metallic weight (kg/m)

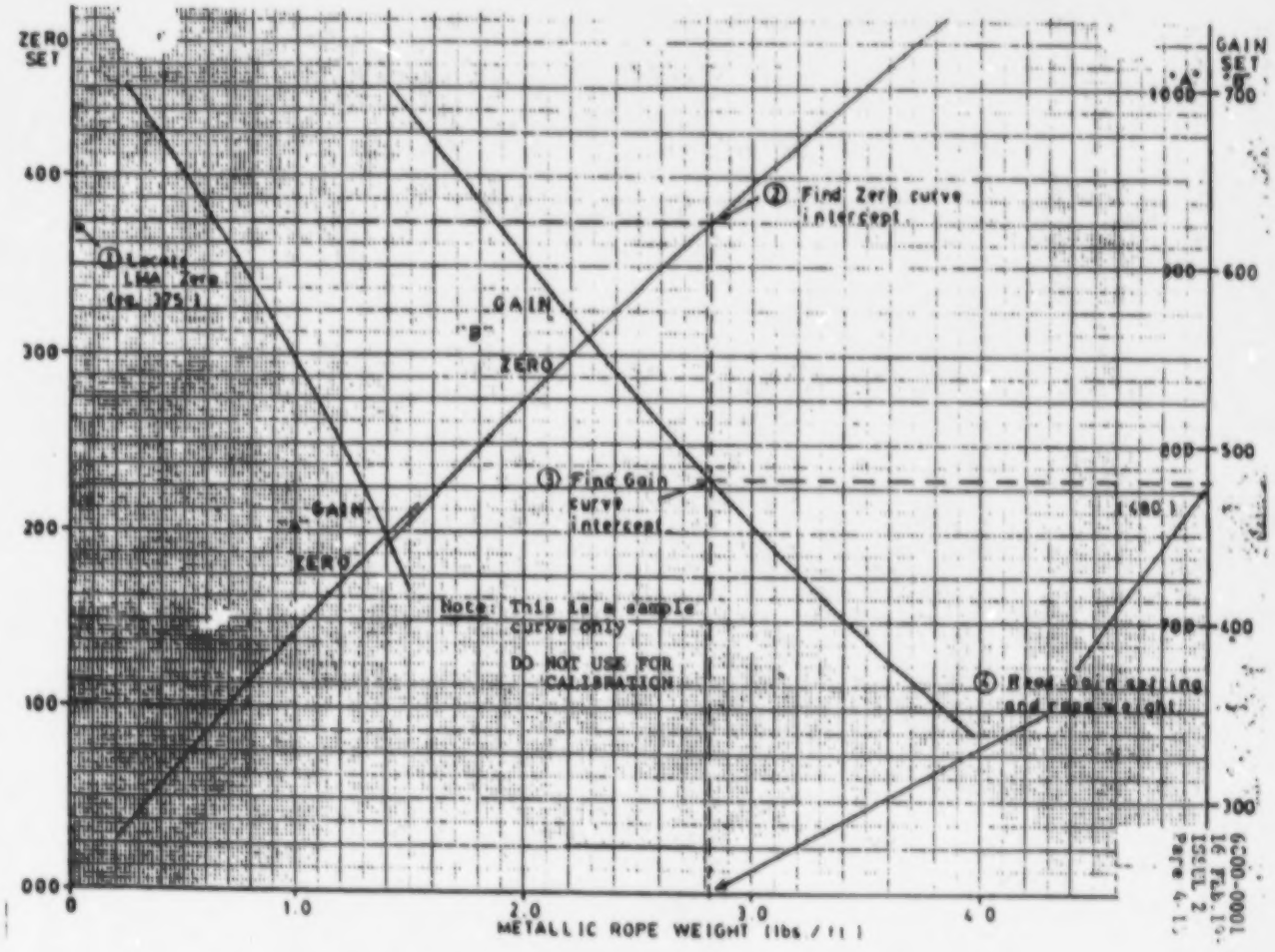


Fig. 3 — Calibration curve for Magnograph (note: 1 lb/ft = 1.488 kg/m)

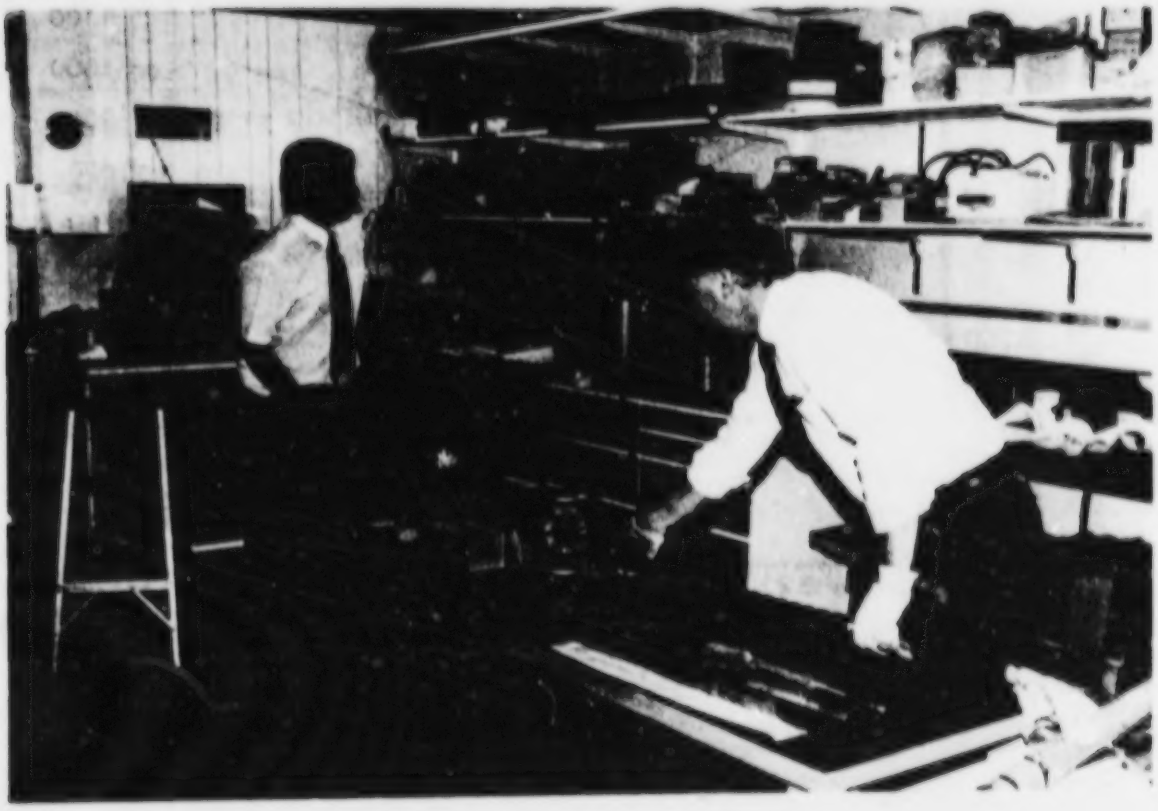


Fig. 2 — Laboratory tests to measure TMA

Fig. 2 (continued) —

Laboratory tests to measure TMA

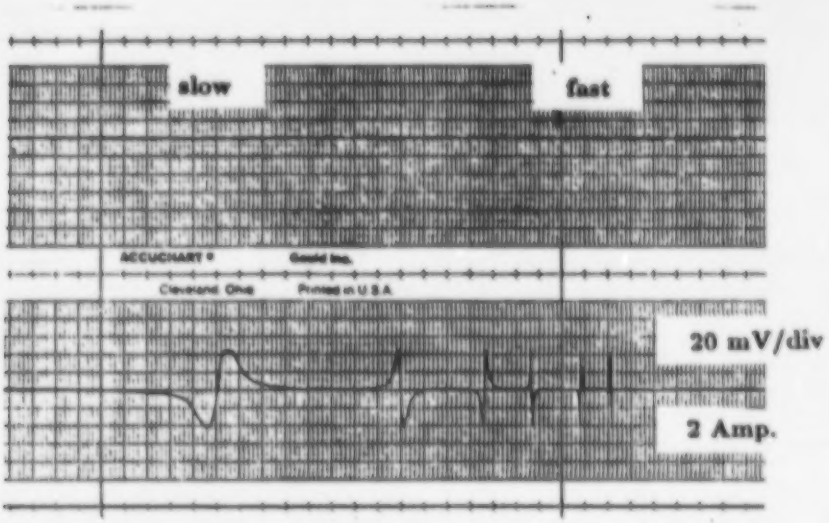


Fig. 4 — Characteristic LF wave-form for Maguograph

Wire Rope Industries Ltd.

Vertical Shaft Mining and Aerial Tramways

Mine Hoisting Ropes — 6 x 27 F.C. Flattened Strand (Triangular)

Diameter		Mass	Nominal Breaking Load							
			Standard Tensile			I.H.T.			U.H.T.	
Nom.	Act.	Nom.	1770	MPa 1620	1530		MPa			MPa
mm	mm	kg/m	kN				kN			kN
19.0	19.4	1.44	245	254	267	276	289	298	311	320
22.2	22.7	1.98	334	347	364	378	391	405	423	438
25.4	25.9	2.59	440	458	480	498	518	538	558	
28.6	29.2	3.30	560	587	609	638	658	685		
31.7	32.4	4.08	694	725	752	783	814	845		
34.9	35.8	4.94	841	878	912	947	988	1010		
38.1	38.9	5.88	1001	1045	1090	1134	1179			
41.3	42.1	6.93	1179	1228	1281	1334	1357			
44.4	45.3	7.99	1361	1419	1477	1535	1557			
47.6	48.5	9.06	1548	1615	1686	1713				
50.8	51.8	10.27	1753	1828	1904	1935				
54.0	55.0	11.81	1975	2080	2148	2180				
57.1	58.3	12.72	2215	2313	2357					

Intermediate sizes are available upon request.

Fig. 5a$_1$ — Sample catalogue sheet; 6×27 flattened strand (metric)

Mine Hoisting Ropes — 6 x 27 F.C. Flattened Strand (Triangular)

Diameter		Mass	Nominal Breaking Load							
			Standard Tensile			U.H.T.			U.H.T.	
			Long Tons/in²			Long Tons/in²			Long Tons/in²	
			110	120	130	130	135	140	145	150
Nom.	Act.	Nom.	Lbs./Ft.	Lbs. (000)			Lbs. (000)			Lbs. (000)	
in.	in.	Lbs./Ft.								
5/8	.785	.97	55	57	60	62	65	67	70	72
3/4	.892	1.33	75	78	82	85	88	91	95	98
7/8	1.020	1.74	98	103	108	112	116	121	125	
1										
1 1/8	1.148	2.22	126	132	137	143	148	154		
1 1/4	1.275	2.74	156	163	169	176	183	190		
1 3/8	1.403	3.32	189	197	205	213	222	227		
1 1/2	1.530	3.95	225	235	245	255	265			
1 5/8	1.657	4.66	265	276	288	300	305			
1 3/4	1.785	5.37	306	319	332	345	350			
1 7/8	1.910	6.09	348	363	379	385				
2	2.040	6.90	394	411	428	435				
2 1/8	2.165	7.80	444	463	483	490				
2 1/4	2.295	8.55	498	520	530					

Fig. 5a$_2$ — Sample catalogue sheet; 6×27 flattened strand (imperial)

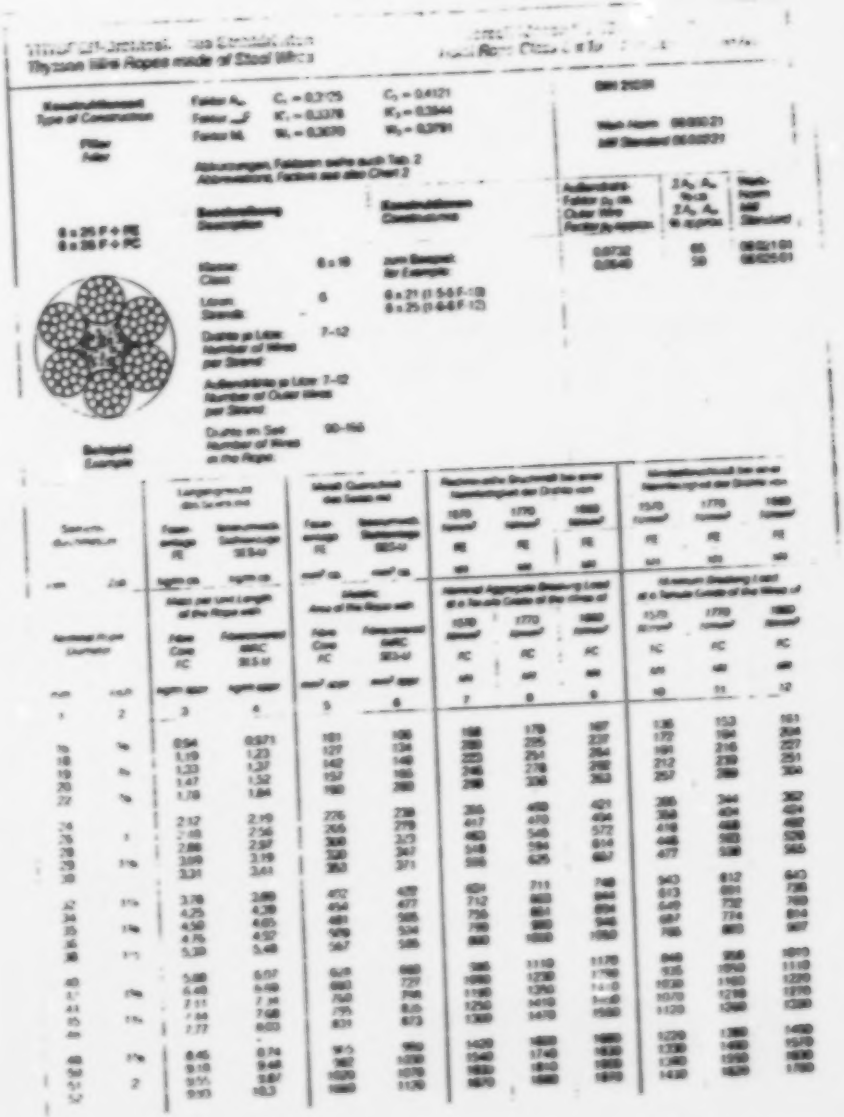
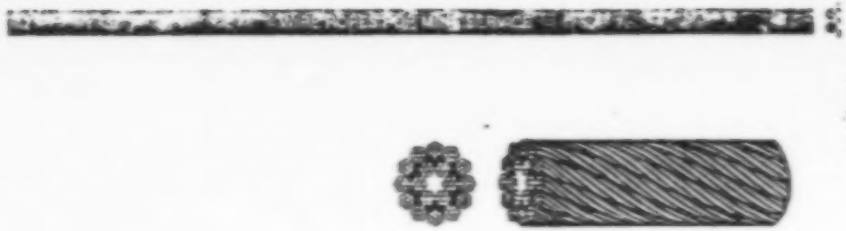


Fig. 5b — Sample catalogue sheet; 6×19 class, parallel lay ropes



18 x 7 L.C. Nylon Core Balance Ropes

Diameter	Mass	Nominal Breaking Load	
		1570 MPa	1620 MPa
mm	kg/m	kN	kN
19	1.48	182	205
22	1.86	248	275
25	2.53	321	355
29	3.21	408	449
32	3.94	496	551
35	4.75	600	663
38	5.65	716	790
41	6.61	836	922
44	7.67	966	1103
48	8.76	1106	1225
51	9.94	1259	1389
54	11.52	1458	1608
57	12.88	1625	1796
60	14.27	1804	1985
64	15.79	1993	2203

Diameter	Mass	Nominal Breaking Load	
		1570 MPa	1620 MPa
in.	lbs./ft.	lbs. (kN)	lbs. (kN)
¾	0.99	41	46
⅞	1.22	56	62
1	1.70	72	80
1⅛	2.18	91	101
1¼	2.65	112	124
1⅜	3.19	135	149
1½	3.80	161	178
1⅝	4.44	188	207
1¾	5.30	224	248
1⅞	5.80	249	275
2	6.68	283	312
2⅛	7.74	327	362
2¼	8.64	365	404
2⅜	9.59	406	448
2½	10.59	448	496

Fig. 6a — Sample catalogue sheet; 18×7 balance ropes

34 x 7 L.C. Nylon Core Balance Ropes

Diameter	Mass	Nominal Breaking Load	
		1570 MPa	1620 MPa
mm	kg/m	kN	kN
10	1.5	182	205
22	2.1	258	289
25	2.7	334	369
29	3.4	418	463
32	4.2	516	569
35	5.2	633	699
38	6.0	738	814
41	7.1	881	974
44	8.3	1023	1130
48	8.4	1163	1290
51	10.7	1321	1459
54	12.2	1512	1672
57	13.8	1686	1864
60	15.2	1873	2073
64	16.7	2068	2288

Diameter	Mass	Nominal Breaking Load	
		1570 MPa	1620 MPa
in.	lbs./ft.	lbs. (kN)	lbs. (kN)
⅜	1.0	41	46
½	1.4	58	65
1	1.8	75	83
1⅛	2.3	94	104
1¼	2.8	116	128
1⅜	3.5	140	155
1½	4.0	166	183
1⅝	4.8	196	219
1¾	5.5	230	254
1⅞	6.3	262	290
2	7.2	297	328
2⅛	8.2	340	376
2¼	9.2	379	419
2⅜	10.2	421	466
2½	11.2	465	514

Fig. 6b — Sample catalogue sheet; 34×7 balance ropes

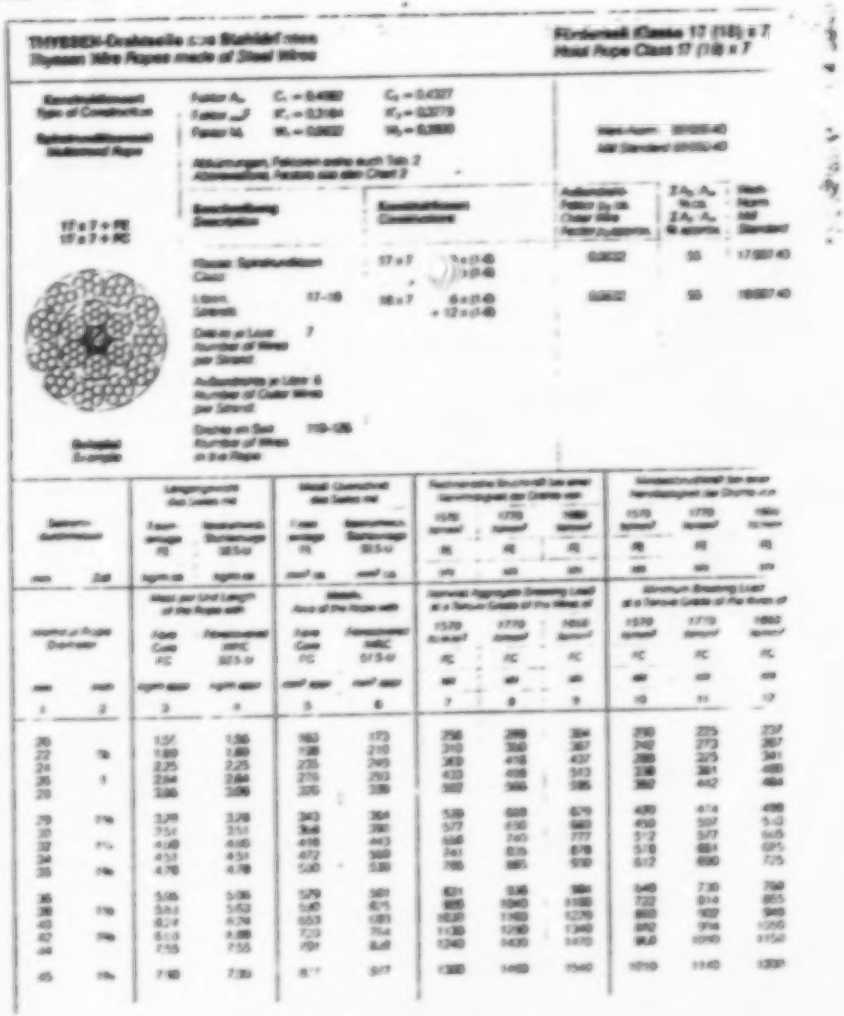


Fig. 6c — Sample catalogue sheet; 17 (18)×7 class ropes

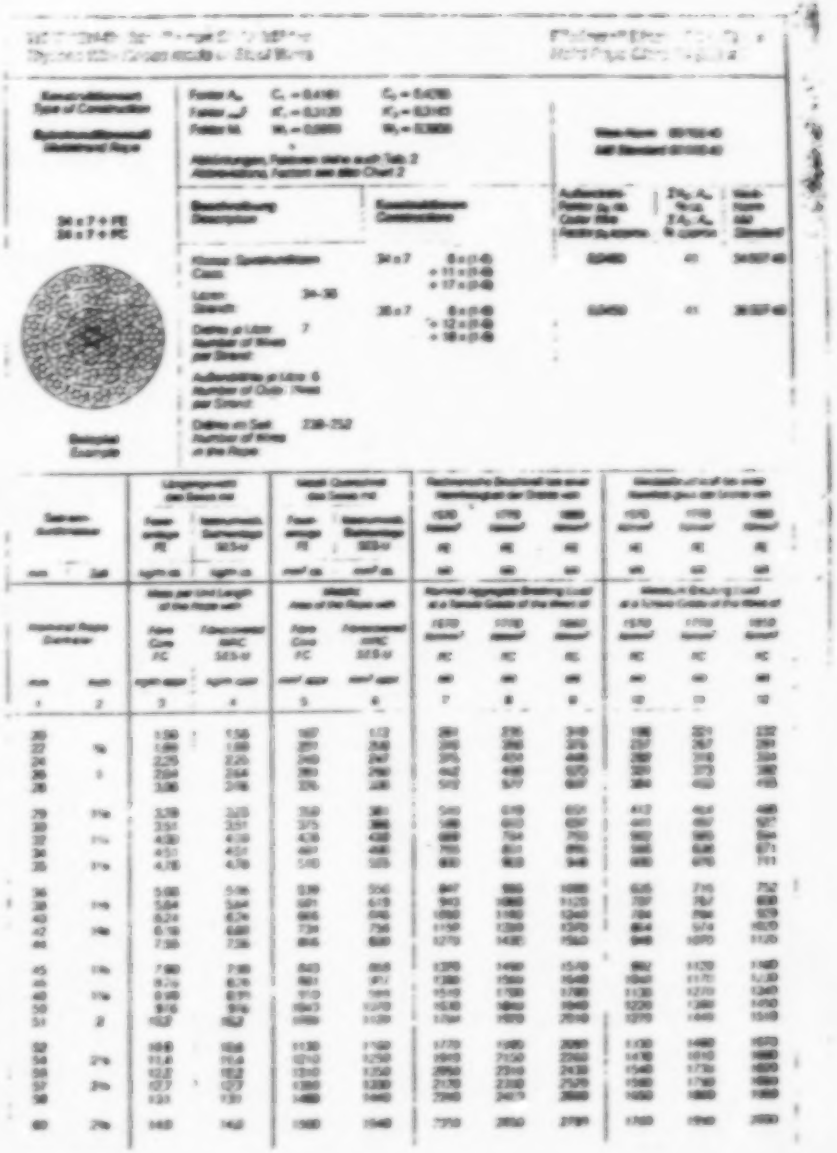


Fig. 6d — Sample catalogue sheet; 34 (36)×7 class ropes

Typical Locked Coil Hoisting Rope

Full Lock Coil Hoisting Ropes

Diameter mm	Mass Kg/m	Nominal Breaking Load kN
16.0	1.31	258
17.5	1.44	250
19.1	1.66	309
20.6	2.20	
22.2	2.76	350
23.8	3.16	418
		479
25.4	3.65	548
27.0	4.13	617
28.6	4.58	697
30.2	5.07	778
31.7	5.58	857
33.3	6.06	947
34.9	6.70	1,038
36.5	7.22	1,136
38.1	7.81	1,230
39.7	8.44	1,330
41.3	8.29	1,445
42.8	10.04	1,564
44.4	10.83	1,674
46.0	11.67	1,803
47.6	12.59	1,923
49.2	13.48	2,065
50.8	14.39	2,192
52.4	15.30	2,332
54.0	16.16	2,472

Intermediate sizes are available upon request

Diameter in.	Mass lb/ft	Nominal Breaking Load tons (2000 lb)
¾	0.86	47.0
7/8	1.10	58.2
1	1.31	68.4
1⅛	1.58	80.6
1¼	1.85	94.0
1⅜	2.12	107.6
1½	2.45	123.2
1⅝	2.77	138.2
1¾	3.09	156.8
1⅞	3.41	174.8
2	3.75	192.6
2⅛	4.07	212.8
2¼	4.53	233.0
2⅜	4.85	255.4
2½	5.25	277.8
2⅝	5.67	298.2
2¾	6.24	324.8
2⅞	6.75	351.6
3	7.29	378.4
3⅛	7.84	405.4
3¼	8.45	432.4
3⅜	9.05	462.0
3½	9.67	492.8
3¾	10.28	524.2
3⅞	10.88	555.6

Fig. 7a — Sample catalogue sheet; Full Locked Coil ropes

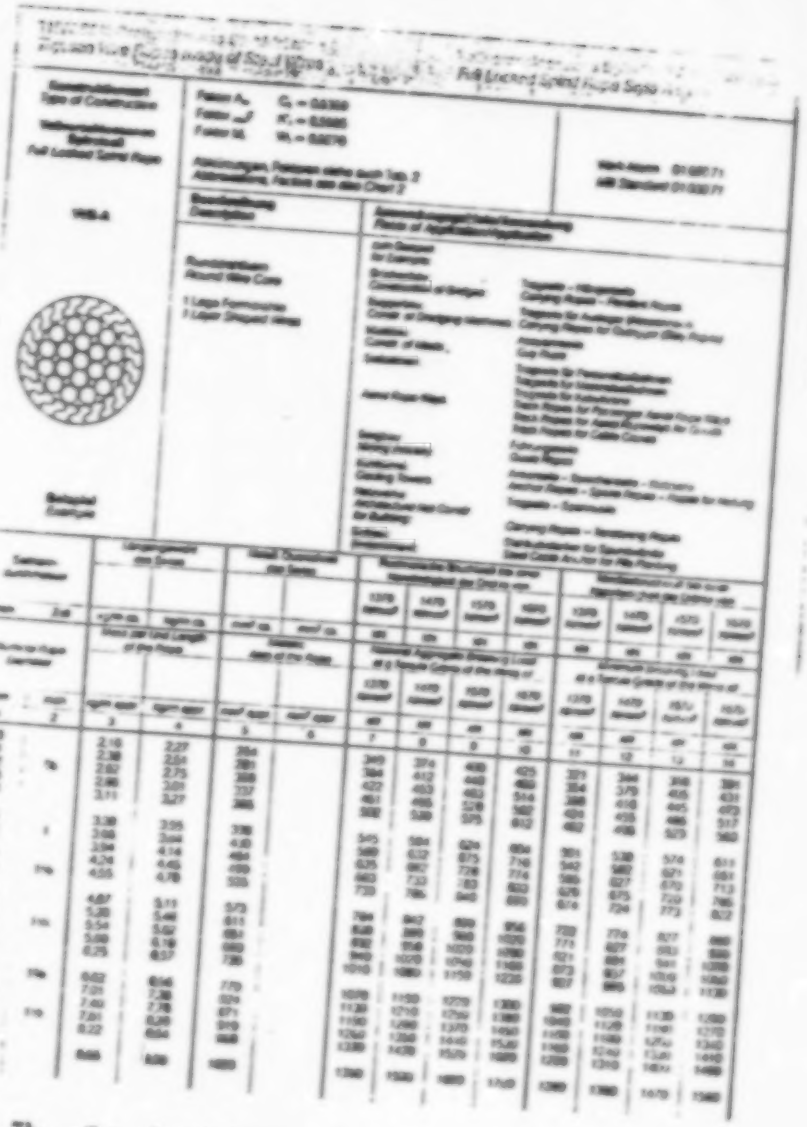


Fig. 7b — Sample catalogue sheet; Full Locked Coil spiral ropes

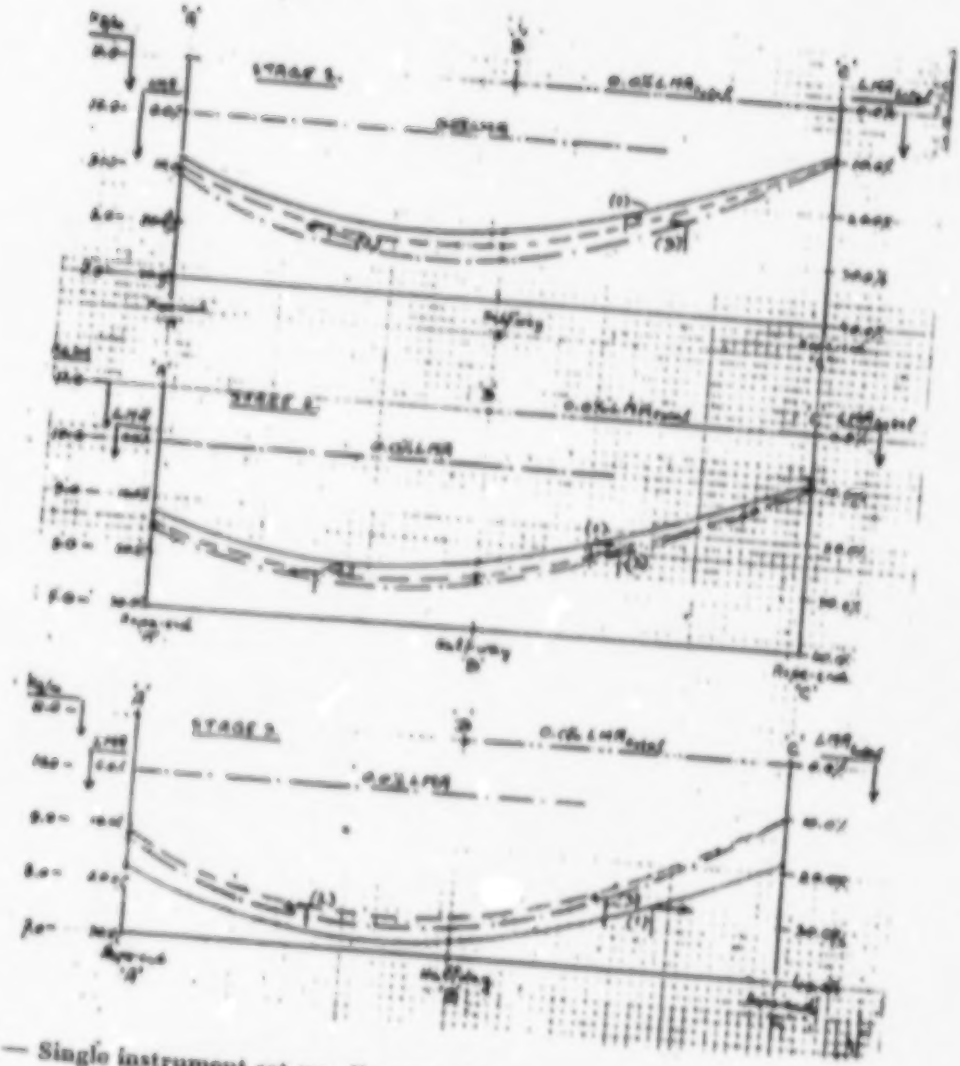
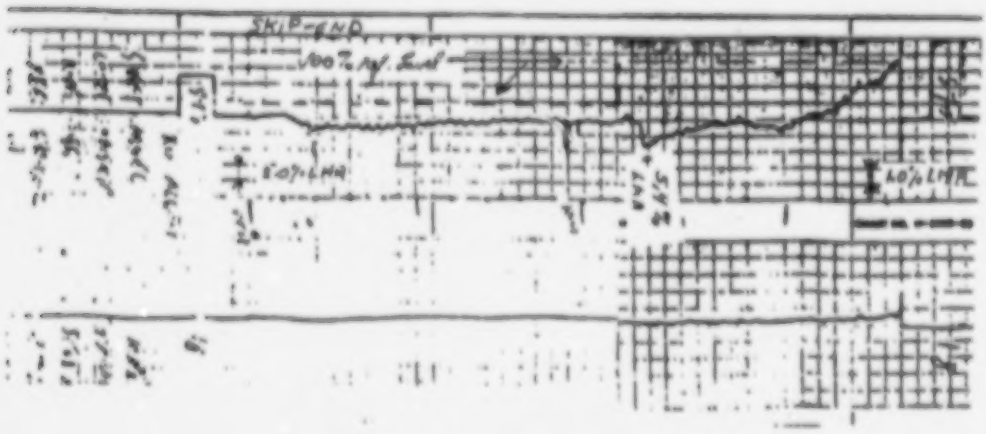


Fig. 8 — Single instrument set-up: disparate LMA chart-readings (theoretical example)

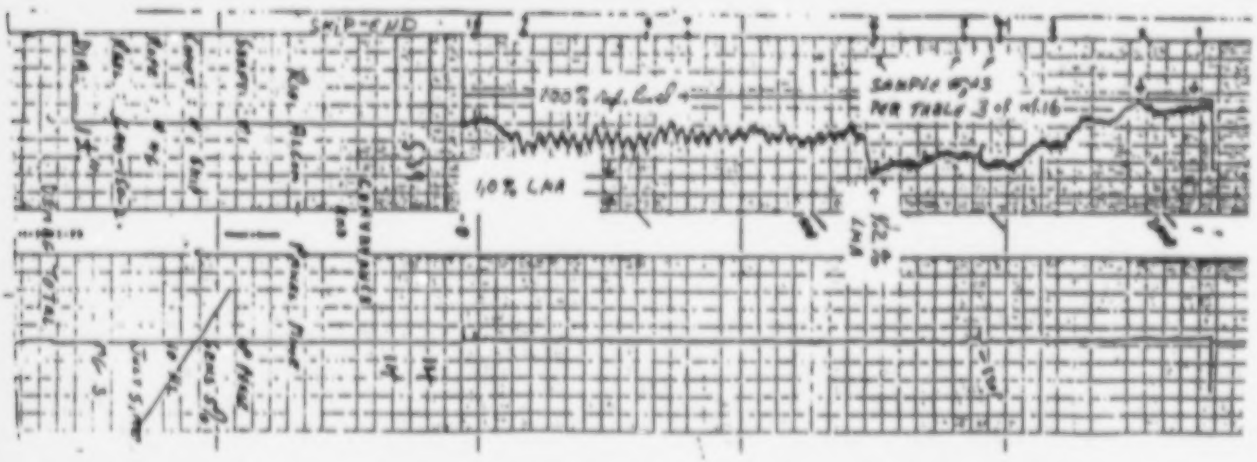
curve (1) — $\%LMA_{total}$

curve (2) — kg/m and %LMA (with calibration at 'C')

curve (3) — %LMA (with calibration at 'A')



(a) in-situ test, 1990 06 21



(b) reel-to-reel test, 1990 07 05

Fig. 9 — Single instrument set-up; disparate LMA chart-readings (operational example)

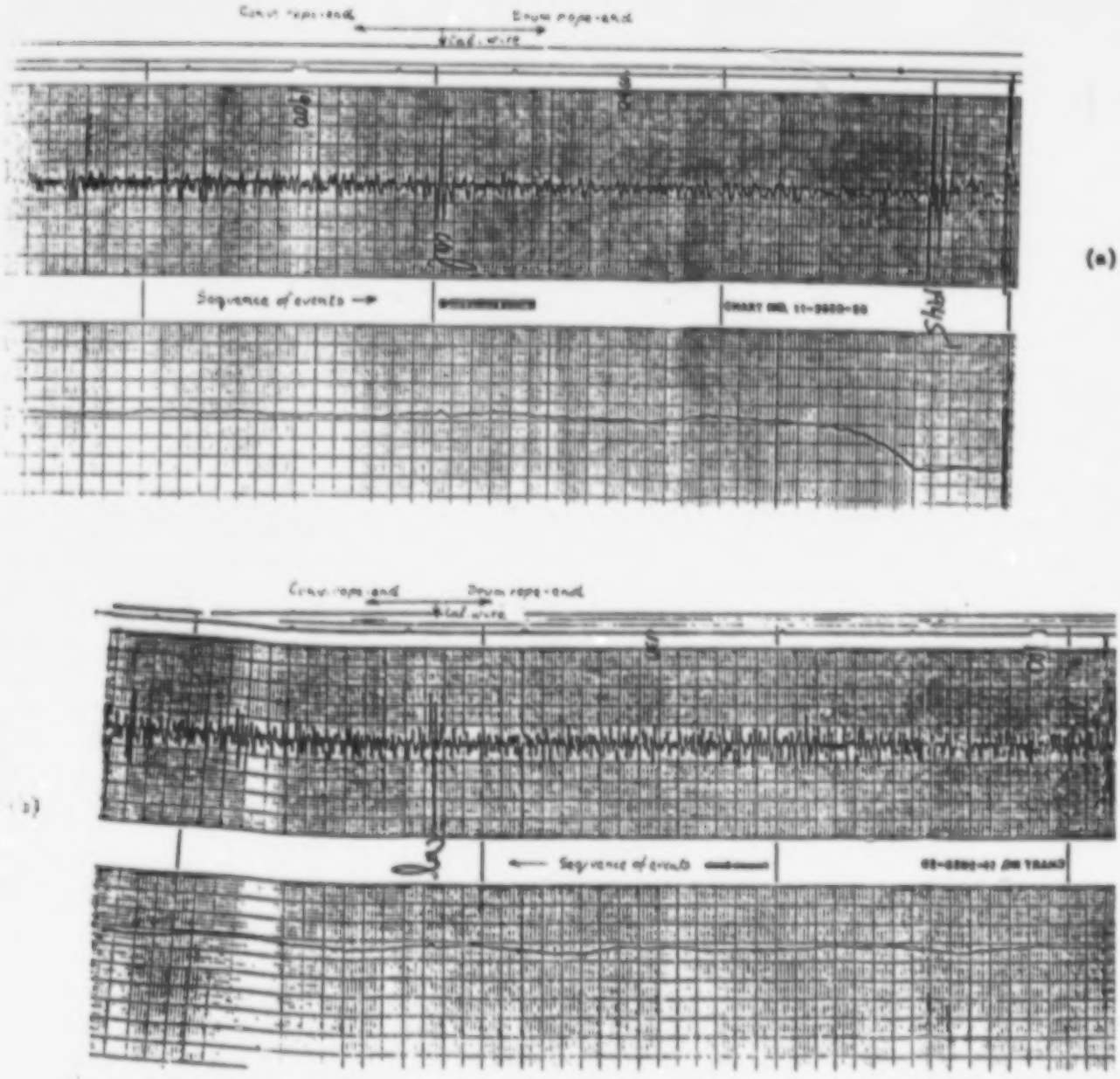


Fig. 10 — Two test set-ups: (a) conveyance rope-end to 'calibration wire' chart segment,

(b) 'calibration wire' to drum rope-end chart segment

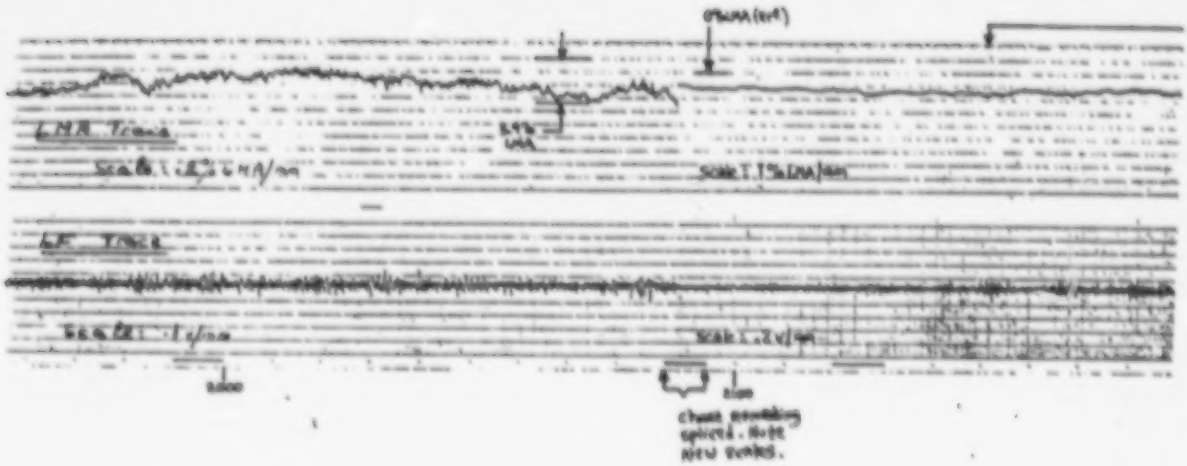


Fig. 11 — Chart segment with two sensitivity settings

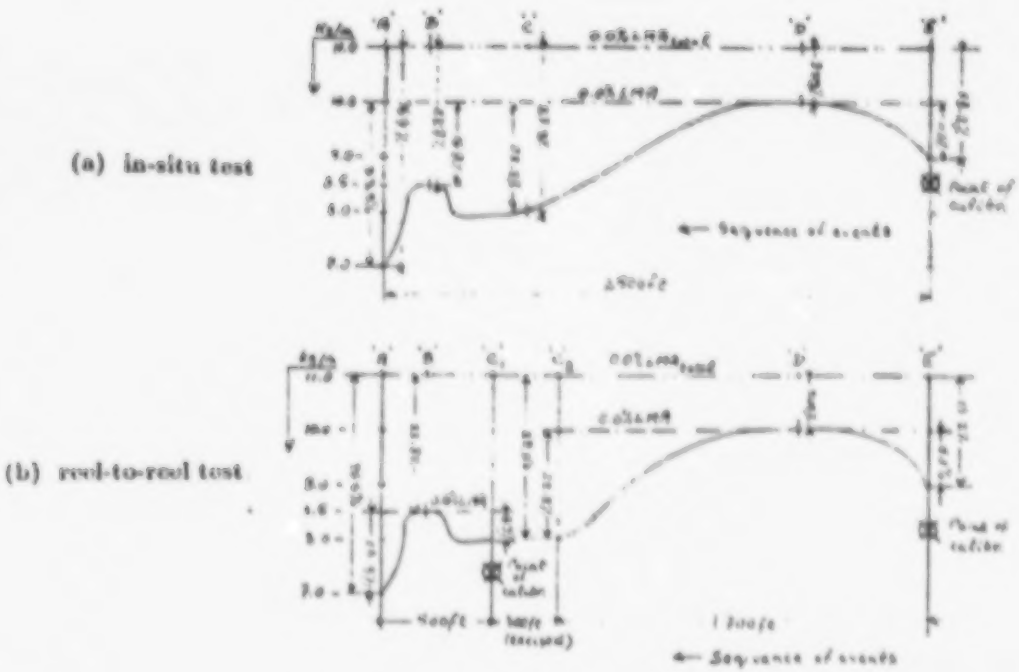
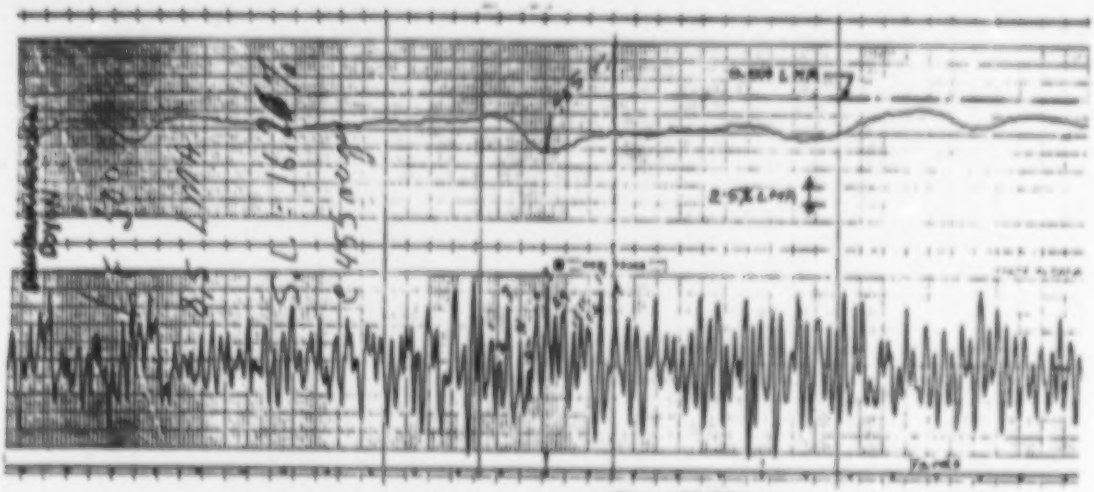


Fig. 12 — Double instrument set-up; disparate LMA chart-readings (theoretical example):

(a) entire rope-length available for testing, and (b) entire rope-length not available for testing



RODIER

SERVICE D'INSPECTION RODIER INC. PAGE 2 DE 7

RAPPORT TECHNIQUE	CLIENT:	RAPPORT #: RR-045
	COMMANDE #:	MINE: DOYON
ESTIMATION DE LA PERTE DE FORCE (S.L.)	PUIT #: 1	COMPARTIMENT #: 1 (SKIP)
	TYPE DE CABLE: 1 1/2" Ø 6 X 27	BOBINE #: 641700-2

ON GOING LF SIGNALS (GRANDE DIVISION)	
1	3.4
2	3.1
3	5.8
4	4.6
5	2.4
6	5.6
7	6.5
8	3.8
9	3.9
10	4.6
11	4.1
12	2.5
13	8.5 (15.43)
14	6.5
15	
16	
17	
18	@ 455 verges
19	
20	
TOTAL:	63.3
AVERAGE:	4.66 (5.457)
PK /AVER	1.82

ESTIMATION POUR CABLES A 6 TORONS INSERT A, B & C

1- F1: Trouver le facteur S.L. sur le graphique: 885

2- Calculer la valeur LF

a) Insert A & B: LF calc = 50 LMA + 5
(grande division) (gain 700, enregistreuse 20 mV)

b) Insert C: LF calc = 85 LMA + 5 7.72
(grande division) (gain 700, enregistreuse 20 mV)

3- F3 = 1-[LF (moyenne) /LF (calc)] 2.68

4- F2 = (1 - F1) F3 + F1 916

5- R.S. = RMA X F2 83.81
S.L. = 100 - R.S. 16.19

PK MODEL: 225 (PK/average) + 552 = F4

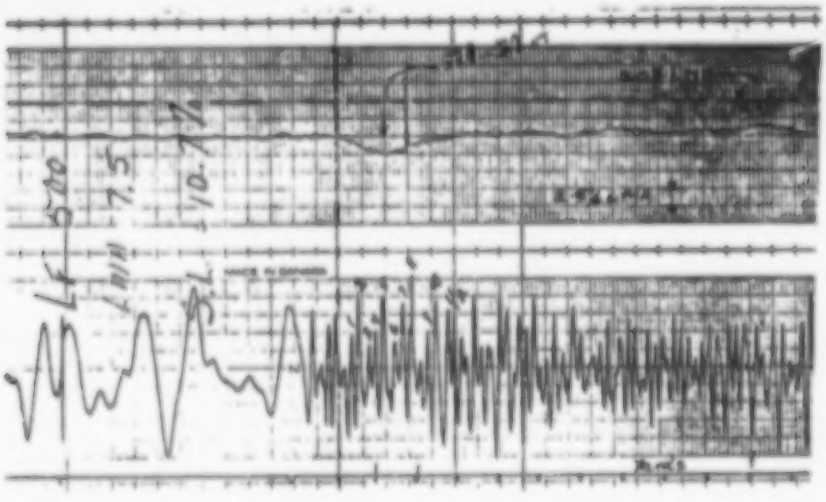
S.L. TOTAL (L.F. < 15 / > 25 average) = S.L. (5) X F4

S.L. =

LEGENDE: S.L. Strength loss
L.F. Local flaws
L.M.A. Loss of metallic area
R.S. Remaining strength
R.M.A. Remaining metallic area (100% - LMA)

RAPPORT ESSAI ORIGINAL: REALISE PAR: M. Rodier DATE: 21-01-88

Fig. 13a — LDS calculation; our rope #7, 455 yard rope-segment



RODIER

SERVICE D'INSPECTION RODIER INC. PAGE 3 DE 7

RAPPORT TECHNIQUE	CLIENT:	RAPPORT #: 88-045
	COMMANDE #:	MINE: DOYON
ESTIMATION DE LA PERTE DE FORCE (S.L.)	PUIT #: 1	COMPARTIMENT #: 1 (SKIP)
	TYPE DE CABLE: 1 1/2" Ø 6 X 27	ORIGINE #: 641700-2

ON GOING LF SIGNALS (GRANDE DIVISION)	
1	6.7
2	7.7
3	3.6
4	3.2
5	6.9
6	4.0
7	4.5
8	8.2 (1488)
9	4.4
10	6.6
11	7.7
12	4.1
13	
14	
15	
16	
17	
18 @ 521 - 522 verges	
19	
20	
TOTAL	67.6
AVERAGE	5.63/10.22
PE /AVER	1.46

ESTIMATION POUR CABLES A 6 TORONS INSERT A, B & C

1- F1: Trouver le facteur S.L. sur le graphique .901

2- Calculer la valeur LF

a) insert A & B: LF calc = 50 LMA + 5
(grande division) (gain 700, enregistreuse 20 mV)

b) insert C: LF calc = 85 LMA + 5 6.875
(grande division) (gain 700, enregistreuse 20 mV)

3- F3 = 1-[LF (moyenne) /LF (calc)] .487

4- F2 = (1 - F1) F3 + F1: .949

5- R.S. = RMA X F2: 87.8
S.L. = 100 - R.S.: 12.2

PK MODEL: 225 (PK/average) + 552 = F4 68

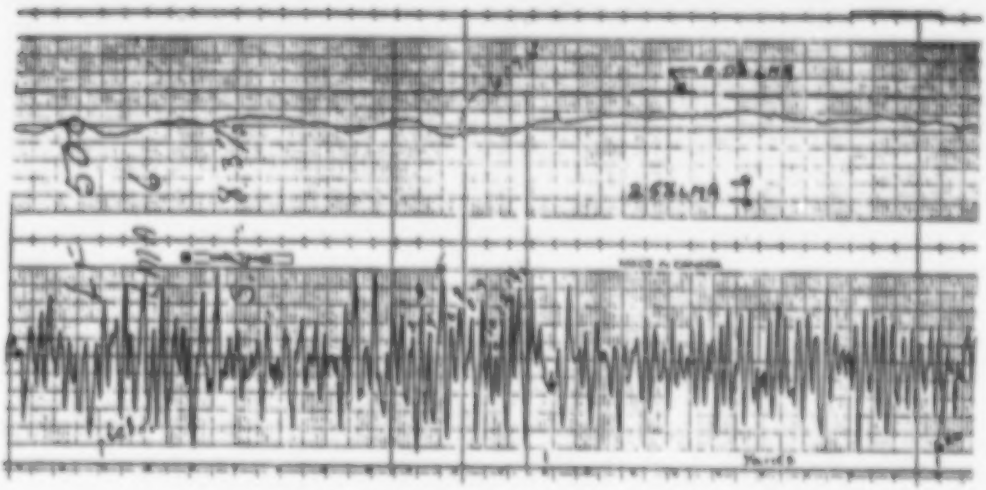
S.L. TOTAL (LF < 15 average) = S.L. (5) X F4
> 25

S.L. = 10.78

LEGENDE: S.L. Strength loss
L.F. Local flaws
L.M.A. Loss of metallic area
R.S. Remaining strength
R.M.A. Remaining metallic area (100% - LMA)

RAPPORT ESSAI ORIGINAL REALISE PAR: M. Rodier DATE: 21-01-89

Fig. 13b — LBS calculation; our rope #7, 521 yard rope-segment



ROGLER

SERVICE D'INSPECTION ROGLER INC.

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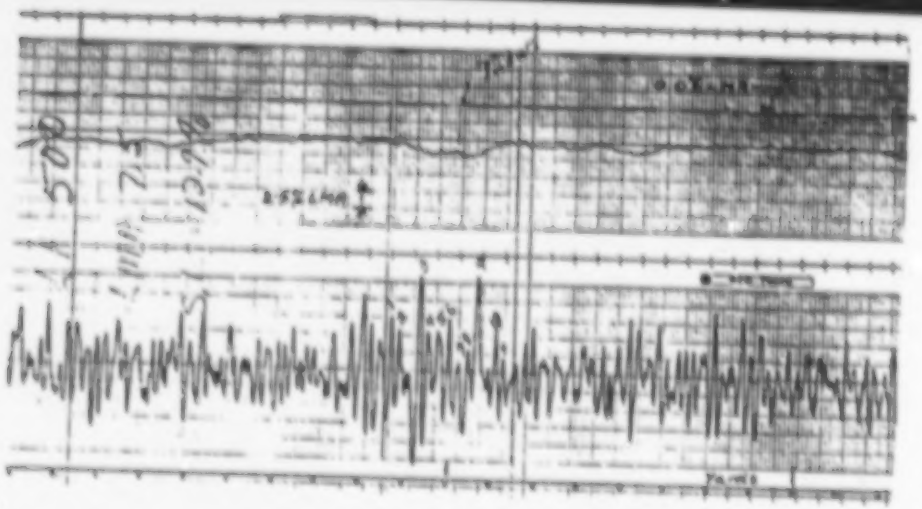
RAPPORT TECHNIQUE	CLIENT:	RAPPORT #: 89-045
	COMMANDE #:	MINE: DOYON
ESTIMATION DE LA PERTE DE FORCE (S.L.)	PUIT #: 1	COMPARTIMENT #: 1 (SKIP)
	TYPE DE CABLE: 1 1/2" Ø 6 X 27	BOBINE #: 641700-2

ON GOING LF SIGNALS (GRANDE DIVISION)	ESTIMATION POUR CABLES A 6 TORONS INCLUANT A, B & C
1 39	1- F1: Trouver le facteur S.L. sur le graphique 917
2 39	2- Calculer la valeur LF
3 84 (15.25)	a) Insert A & B (grande division) LF calc = 50 LMA + S (gain 700, enregistreuse 20 mV)
4 51	
5 81	b) Insert C (grande division) LF calc = 85 LMA + S 96 (gain 700, enregistreuse 20 mV)
6 63	
7 42	3- F3 = 1-[LF (moyenne) /LF (calc)] 714
8 37	4- F2 = (1 - F1) F3 + F1 976
9 80	5- RS = RMA X F2 917
10 25	SL = 100 - RS 83
11 28	
12 44	PK MODEL 225 (PK/average) = 552 F4
13 77	SL TOTAL (LF < 15 average) = SL (5) X F4
14 50	> 25
15	SL =
16	
17	
18 @ 609 verges	
19	
20	
TOTAL: 74	
AVERAGE: 5.29 (9.6)	
PK /AVER: 1.59	

LEGENDE: S.L. Strength loss
L.F. Local flaws
L.M.A. Loss of metallic area
R.S. Remaining strength
R.M.A. Remaining metallic area (100% - LMA)

RAPPORT ESSAI ORIGINAL	REALISE PAR:	DATE: 21-01-89

Fig. 13c — LBS calculation; our rope #7, 609 yard rope-segment



RODDIER

SERVICE D'INSPECTION RODDIER INC.

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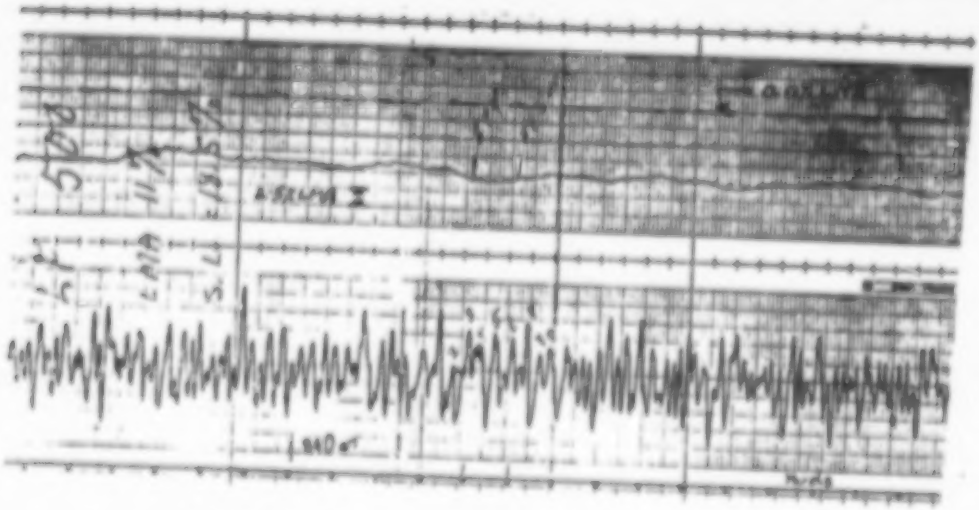
RAPPORT TECHNIQUE	CLIENT:	RAPPORT #: 88-045
	COMMANDE #:	MINE: DOYON
ESTIMATION DE LA PERTE DE FORCE (S.L.)	PUIT #: 1	COMPARTIMENT #: 1 (SKIP)
	TYPE DE CABLE: 1 1/2" Ø 6 X 27	BOBINE #: 641700-2

OR GOING LF SIGNALS (GRANDE DIVISION)	ESTIMATION POUR CABLES A 6 TORONS INSERT A, B & C
1 5.9	1- F1: Trouver le facteur S.L. sur le graphique 90.1
2 4.4	2- Calculer la valeur LF
3 10.5 (19.1)	a) Insert A & B LF calc = 5% LMA = 5
4 6.4	(grande division) (gain 700, enregistreur à 20 mV)
5 3.5	b) Insert C LF calc = 8.5 LMA = 8 6.87
6 5.8	(grande division) (gain 700, enregistreur à 20 mV)
7 3.0	3- F3 = 1- [LF (moyenne) /LF (calc)] .415
8 4.7	4- F2 = (1 - F1) F3 + F1 .942
9 6.9	5- R.S. = RMA X F2 87.1
10 4.3	S.L. = 100 - R.S. 12.9%
11 3.5	PK MODEL 2.25 (PK/average) = 5.52 = F.1
12	S.L. TOTAL (L.F. $\begin{cases} < 1.5_{average} \\ > 2.5 \end{cases}$) = S.L. (5) X F.1
13	S.L. =
14	
15	
16	
17	
18 @ 722 verges	
19	
20	
TOTAL 58.9	
AVERAGE 5.35 (9.72)	
PK FACTOR 1.96	

LEGENDE: S.L. Strength loss
L.F. Local flaws
L.M.A. Loss of metallic area
R.S. Remaining strength
R.M.A. Remaining metallic area (100% - LMA)

RAPPORT ESSAI ORIGINAL	REALISE PAR: M. Rodier	DATE: 21-01-89

Fig. 13d — LDS calculation; our rope #7, 722 yard rope-segment



ROD-LEAK

SERVICE D'INSPECTION ROGER INC.

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RAPPORT TECHNIQUE	CLIENT:	RAPPORT #: 88-045
	COMMANDE #:	MINE: BOYDIN
ESTIMATION DE LA PERTE DE FORCE (S.L.)	PUIT #: 1	COMPARTIMENT #: 1 (SKIP)
	TYPE DE CABLE: 1 1/2" B 6 X 27	BOBINE #: 641700-2

ON GOING LF SIGNALS (GRANDE DIVISION)	
1	5.0
2	3.1
3	5.5
4	1.9
5	5.7 (0.34)
6	3.9
7	4.2
8	4.2
9	2.4
10	
11	
12	
13	
14	
15	
16	
17	
18 @ 844 - 845 verges	
19	
20	
TOTAL	35.9
AVERAGE	3.99 (7.24)
LF. /AVER	1.45

ESTIMATION POUR CABLES A 6 TORONS INSERT A, B & C

1- F1: Trouver le facteur S.L. sur le graphique 846

2- Calculer la valeur LF

a) Insert A & B (grande division) LF calc = 50 LMA ÷ S (gain 700, enregistreuse 20 mV)

b) Insert C (grande division) LF calc = 85 LMA ÷ S 9.65 (gain 700, enregistreuse 20 mV)

3- F3 = 1-[LF (moyenne) /LF (calc)] 26

4- F2 = (1 - F1) F3 + F1 886

5- R.S. = RMA X F2 78.85
S.L. = 100 - R.S. 21.15

PK MODEL 225 (PK/average) ÷ 552 = F4 674

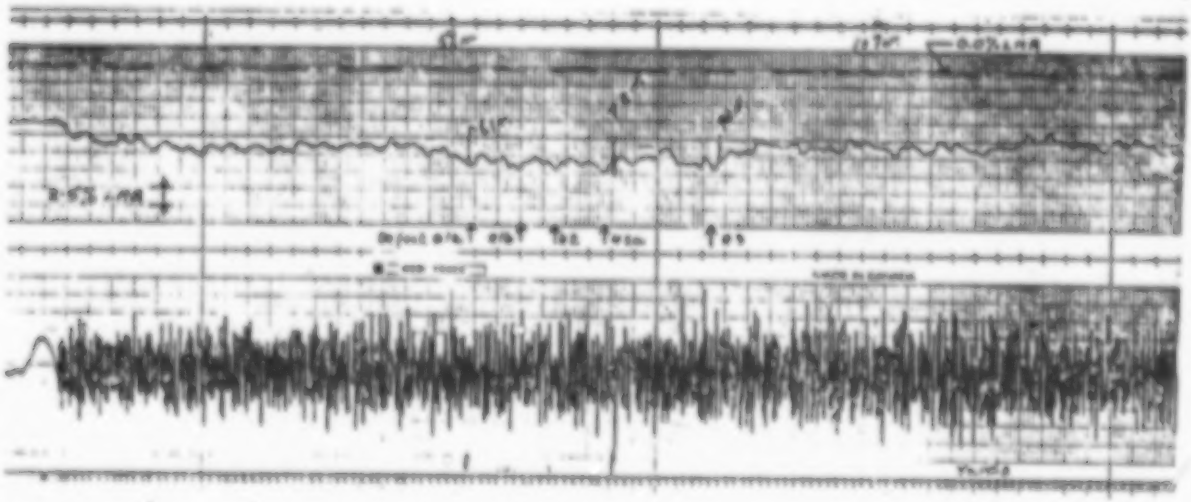
S.L. TOTAL (LF < 15 overage) = S.L. (5) X F4
> 25

S.L. = 18.58

LEGENDE: S.L. Strength loss
L.F. Local flaws
L.M.A. Loss of metallic area
R.S. Remaining strength
R.M.A. Remaining metallic area (100% - LMA)

RAPPORT ESSAI ORIGINAL | REALISE PAR: M. Roger | DATE: 21-01-88

Fig. 13c — LBS calculation; our rope #7, 844 yard rope-segment



RODIER

SERVICE D'INSPECTION RODIER INC.

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RAPPORT TECHNIQUE	CLIENT:	RAPPORT #: 89-186
	COMMANDE #: verbal	MINE: DOYON
ESTIMATION DE LA PERTE DE FORCE (S.L.)	PUIT #: --	COMPARTIMENT #: --
	TYPE DE CABLE: 1 1/2" Ø 6 X 27	CABLE #: 7

GO GOING LF SIGNALS (GRANDE DIVISION)	
1	5.5
2	3.9
3	4.4
4	4.7
5	3.3
6	5.3
7	4.4
8	2.4
9	5.1
10	2
11	2.9
12	3.2
13	4.7
14	
16	
16	
17	corrigé 4.53
18	6.79
19	
20	
TOTAL:	51.8
AVERAGE:	3.98
PK /AVER:	1.58

ESTIMATION POUR CABLES A 6 TORONS INSERT A, B & C

1- F1: Trouver le facteur S.L. sur le graphique: 607
13.5 LMA

2- Calculer la valeur LF

a) Insert A & B: LF calc = 50 LMA + 5
(grande division) (gain 700, enregistreuse 20 mV)

b) Insert C: LF calc = 85 LMA + 5 11.97
(grande division) (gain 700, enregistreuse 20 mV)

3- F3 = 1- | LF (moyenne) /LF (calc) | .266

4- F2 = (1 - F1) F3 + F1: .858

5- R.S. = RMA X F2: 74.2
S.L. = 100 - R.S.: 25.8 %

PK MODEL: 225 (PK/average) + 552 = F4 .662

S.L. TOTAL (L.F. < 1.5) + S.L. (5) X F4
> 2.5 average

S.L. = 22.2%

@ 81 VERGES

LEGENDE: S.L. Strength loss
L.F. Local flaws
L.M.A. Loss of metallic area
R.S. Remaining strength
R.M.A. Remaining metallic area (100% - LMA)

15-82

RAPPORT ESSAI ORIGINAL: M. Rodier | REALISE PAR: M. Rodier | DATE: 5 avril 1989

Fig. 14 — LDS calculation; our rope #7, 81 yard rope-segment